# Use of Lean and Building Information Modeling (BIM) in the Construction Process; Does BIM make it Leaner?

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# Use of Lean and Building Information Modeling (BIM) in the Construction Process; Does BIM make it Leaner?

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# List of Abbreviations

**APICS:** Advancing Productivity, Innovation, and Competition Success

**BIM:** Building information modeling

**ER:** Emergency rooms

**ENR:** Engineering News Records

**GC:** General Contractor

**ICU:** Intensive Care Units

**IPD:** Integrated Project Delivery

**JIT:** Just in time

**OR:** Operation room

**PACU:** Post Anesthesia Care Unit

**RFI:** Request for information

**SF**: Square Feet

**TQM:** Total quality management

**VDC:** Virtual Design and Construction

**WIP:** Work in progress

## Summary

Construction productivity lags behind most industries. In general, the process of construction is carried out in several smaller processes. For the overall construction process to be successful, continuity between these smaller processes must be achieved. This has been the persistent goal of construction productivity improvement for decades now. Waste is generated between the continuing activities by the unpredicted release of work and the arrival of resources. However, in recent decades the construction industry has a great need to improve its productivity, quality and incorporate new technologies to the industry due to increased foreign competition.

In the late 1980s, researchers started looking at solving this problem in a more general and structured way based on the philosophy and ideology of lean production. In lean, adopting waste identification/reduction, or meeting the client's needs with minimal resources addresses the performance improvement. With recent developments in the construction industry, introduction of building information modeling (BIM) has had a significant influence on leaner construction. They are both complementary in several important ways. Various studies conducted exhibit that BIM is very crucial in reducing the project cost, site conflicts, project duration, error reduction, better and faster design development, and so on. This brings the question; can BIM be used as a tool for leaner construction?

The objective of this thesis is to determine how BIM is helping achieve a leaner construction. More and more companies are adopting BIM as an acceptable waste reduction tool. A comprehensive study of lean theory and BIM was conducted, underscoring ways for BIM to help achieve leaner construction. The research was broadly conducted in three different parts. In the first part, a synthesis is drawn from a literature study to show that BIM helps reduce waste, helps in implementing lean techniques, and achieves lean principles. The second part focuses on the data acquired from a construction company to show that BIM helps reduce project cost, duration and conflicts. The third and the last part focused on getting the perspective view of different professionals in the construction industry on BIM by conducting focus interviews. A comprehensive conclusion was derived based on the findings from the three methods adopted.

# Chapter 1:

## Literature Study: Introduction

Construction productivity is a big challenge all over the world. It's a well-known fact that construction productivity lags behind that of manufacturing. The occupational safety of the construction industry is the worst when compared to other industries and the quality of the constructions industry is not sufficient.

According to a survey conducted by Government Statistical Service in 1998 in United Kingdom (UK), the construction industry produces over 70 million tons of waste, which is about four times the rate of household waste production produced by every person in the UK every week (Keys et.al, 1998).

Construction, being one of the oldest industries, is viewed as a set of activities aimed at a certain output (Koskela, 1992). The process of construction is divided into its constituent elements and for each of that element the costs of labor and materials are estimated. Also certain amount of time to complete each activity is allotted. It is assumed that total process consists of sub processes, which converts an input into an output and can only be realized separately. Decisions are made at each stage of the design and construction process, which indirectly or directly, create physical waste. The process of waste generation through design is complex when a single product, a building or HVAC system for example, can have a large number of materials and processes to realize the product (Koskela, 1992). Additionally, the issue is made more complex when further creators of waste are added during sub-contract and construction phases (Keys, et .al, 1998). This lack of a unified conceptual and theoretical framework in construction has been persistent in spite of the realization of flaws of the activity model. The focus on activities conceals the waste generated between the continuing activities by unpredicted release of work and the arrival of resources. In other words, current forms of production and activities focus on activities and ignore flow and value considerations (Koskela, 1992, Koskela and Huovila, 1997).

Many variables and restraints affect the design process that in turn affects the wastes arising and the resultant opportunities for designing out waste. Such issues include materials choice, complexity, communication and coordination.

With the increased foreign competition, the scarcity of skilled labor and the need to improve construction quality, there is an urgent demand to raise productivity, quality, and incorporate new technologies to the industry (Koskela, 1992).

Pertaining to the challenges faced by construction industry, several research and studies have been carried out for the past decades to identify the causes of the problems plaguing the construction industry (Koskela, 1992). The earlier researches dealt only about the end side of the construction process with introduction of new technologies and equipment to speed up the construction process and improve the overall construction productivity. With the lean construction paradigm, construction industry is being viewed as an industry with the possibilities of implementing these new lean perspectives of production concepts in the construction processes to optimize the overall construction performance on construction stage as well as design stage. However, according to Alarcon (1994), there has been little interest in this production philosophy as the people involved are skeptical about the implications of the production philosophy on construction process and are not sure if it will have any significant impact on the productivity improvement.

The new construction production philosophy is laid on the concepts of conversions and flow. Therefore, performance improvement opportunities in construction can then be addressed by adopting waste identification/reduction strategies in the flow processes in parallel with value adding strategies with the introduction of new management tools and with proper trainings and education program.

A relatively new tool that is increasingly getting popular is Building Information Modeling (BIM), which has been playing a major role in reducing construction waste. BIM involves representing a design as objects that carry their geometry, relations and attributes (Chuck Eastman, 2009). Separate drawings for contract documents and then developing a separate set of detail drawings are considered waste and inefficiency in terms of cost and time. BIM not only helps reduce this waste and inefficiency but also helps in reducing the potential for litigation (Chuck Eastman, 2009). Thus, BIM helps enhance the lean outcomes in any company/project that is on a lean journey (Sacks, et.al, 2010).

Both Lean and BIM are effecting fundamental change in the AEC industry by reducing waste and inefficiency (Sacks, Et.al, 2010). Therefore, this thesis intends to address the question “is BIM a tool for leaner construction?”

# 1.1. Construction Wastes

## *1.1.1. Introduction*

What is Waste?

Toyota defines waste as:

"Anything that is different from the minimum quantity of equipment, materials, parts and labor time that is absolutely essential for production." - (Alacorn, 1995)

In general, the lean production and lean construction paradigm sees that all those activities that produce cost, direct or indirect, but do not add value or progress to the product as waste. Waste is easily measurable when it's measured in terms of the cost but very difficult to measure when it's measured in terms of efficiency of the processes, equipment or personnel. This is due to the reason that optimal efficiency is not always known (Alarcon, 1995).

Significant research has been done related to waste in the construction industry. However, most of the studies tend to focus on the waste of materials, which is only one of the sources involved in the construction process. The flow aspects of the construction have been historically neglected. Hence the current construction demonstrates a significant amount of waste, loss of value and non-value adding activities (Formoso, et.al, 1999).

According to Koskela (1998), there has never been enough research to observe all the wastes in a construction process. However, the figures presented may not hold universal as the research is done and shared mainly by leading companies that reflect best practices. Also a wide variation may be present due to local conditions, project types, construction methods etc. However, some of the conclusions that can be drawn from previous research are as follows; (Formoso, et. al, 1999).

- The nominal costs assumed by the companies in their cost estimates are much lower than the waste of building materials.
- The waste indices reflect a high variability from site to site. Furthermore, often-similar sites present different levels of waste with the same material, which indicates that a considerable portion of waste can be avoided with good waste management.
- As most companies do not apply relatively simple procedures to avoid waste on site, they are not concerned about the material waste. These companies often do have neither well-defined material management policy, nor systematic control of material usage.
- Most building firms do not have enough knowledge to prevent waste.
- A significant portion of waste is caused by problems, which occur in stages that precede production, such as inadequate design, lack of planning, flaws in the material supply system, etc.

Despite the numerous studies and researches on waste in construction, one might wonder why is that the waste control systems are not in practice as a general rule. It is due to the reasons presented below (Formoso, et al, 1999):

- Waste of materials is the main focus of most studies, which is only one of the resources involved in the construction process. This seems to be related to the fact that most studies are based on the conversion model, in which material losses are considered to be synonymous of waste.

- The data collection not only involves a large team of researchers, including the people who are heavily involved in monitoring the work on site but also is very expensive. Consequently the procedures used for research for controlling wastes in research studies are not easily adapted in real time production control systems.
- The results of the research takes so much time that the work being monitored will be finished and hence it limits the impact of those studies in terms of corrective action.
- There is little involvement of the people from the company in both data collection and analysis, since most waste control procedures are external to the organization. As a result, the learning process in the company resulting from those studies tends to be very limited.

Waste can be classified into *unavoidable waste* (or natural waste), in which the investment necessary to its reduction is higher than it's return, and *avoidable waste*, when the cost of waste is significantly higher than the cost to prevent it (Formoso, et.al 1999). The percentage of unavoidable waste in each process depends on the company and on the particular site, since it is related to the level of technological development.

### ***1.1.2. Types of wastes***

The following are the seven types of wastes identified and dealt with in lean practices:

**Waiting Time**

It is considered waste when people, equipment or product waits for other processes or workers to finish an up-stream activity. Wait time also known as delay refers to the periods of inactivity that occur because a preceding activity did not deliver on time or finish completely. In other words, it is related to the idle time caused by lack of synchronization and leveling of material flows, and lack of pace of work by different groups or equipments. The cycle time is increased due to the waiting waste during which no value added activities are performed. Waiting is often caused by poor communication between or among the field functions, support functions or suppliers. It is also caused when equipment needed to complete the upstream task breaks down. Poor coordination between the trades will also cause this waste. Often at a construction site you can see a crew waiting for instructions or materials, or fabrication machine waiting for materials to be cut, or payroll on wait due to late arrivals of the time sheets (Sowards, 2005).

**Motion Waste**

Often, extra steps are taken by people to accommodate inefficient process layouts, defects, reprocessing, over production or excess inventory. These extra activities and efforts lead to motion waste. Motion not only takes time but also adds absolutely no value to either the product or the service. None of the parties involved in the process are benefitting. Work is defined as “to move and to add value at the same time” whereas motion is defined as “to move and to add no value” (Sowards, 2005).

**Processing and Over-Processing waste**

Processing is related to nature of the processing activity, which could be avoided by changing the construction technology. For instance a percentage of mortar is usually wasted when a ceiling is being plastered. (Sowards, 2005)

The term over processing generally refers to unnecessary steps in operations, such as reprocessing, double handling, added communication and double-checking which adds no value to the product or service. Over-processing is often inserted into a process as a result of dealing with defects, overproduction or excess inventory (Sowards, 2005).

**Over production waste**

Overproduction occurs when operations continue after they should have stopped. It's producing more than is needed, faster than needed or before it is needed. This result in product being produced in excess of what's required, products being made too early, and excess inventory carrying costs (Sowards, 2005). It results in unnecessary extra work for workers, making it harder to do priority work.

In construction, over production is observed when shop workers fabricate materials too early or when materials are stockpiled either in warehouse or at the jobsite. Printing more blue prints or more copies of reports can also be categorized as over-production waste. Estimating and bidding jobs that are not won is also a form of this waste (Sowards, 2005).

**Transportation waste**

Transportation waste is any unnecessary motion or movement of products or materials that does not support immediate production. Materials transported to one jobsite to another or materials being transported from jobsite back to the building partner are common examples of transportation waste in construction.

Employees walking around do not add value and these are other examples of waste due to transportation. These occur when workers must go looking for tools, material or information. In the office, when we are looking for files, reports, reference books, drawings, contracts or vendor catalogues, it is waste. Poor planning and organization often cause this waste. It happens because we don't have a designated place for everything (Sowards, 2005).

Transportation not only adds time to the process during which no value-added activity is being performed but also exposes the materials to handling damages. Hence, transportation of materials needs to be minimized as much as possible (Sowards, 2005).

**Inventory waste**

Any material or goods that are in excess of what is required to build the current structure in construction is inventory waste. This includes uncut materials, work in progress, and finished fabrications. If a material is not yet installed and is not being used by the customer, it’s regarded as waste. This includes spare parts, unused tools, consumables, forms, copies, employee stashes, and personal stockpiles. One could argue that the unfinished facility is inventory and is waste until operational.

Though not all inventory can be regarded as waste, excess inventory can quickly build-up and tie-up dollars and resources. All inventories require additional handling and space. Some inventory might be required to perform work in a timely manner, but its still waste that needs to be attacked and reduced. It ties up working capital and space. It must be controlled and continually monitored and annually audited (Sowards, 2005).

So why do contractors really build inventory? This is because, often the contractors deal with unreliable support from shop, suppliers or the delivery system. Sometimes they also build inventory to save money by buying bulk. The money saved in bulk buys is usually eaten up by the hidden, but real costs of holding, managing, and moving inventory. Free shop time also might lead to fabrication ahead of schedule, which results in inventory wastes (Sowards, 2005).

**Correction (or defect) waste**

A product or service that contains errors and requires rework or does not function as designed can be regarded as a correction (or defect) waste. Corrections and defects are anything not done correctly the first time and must be repaired, sorted, re-made or re-done, and as well as materials which are scrapped due to defects (Sowards, 2005).

Some of the wastes identified in this category are wrong installation, defects in fabrication, punch lists and many kinds of change orders. Misunderstanding the customer's requirements or expectations can cause defects. Not meeting the required code is waste. Defects often come from not having and using standard processes (Sowards, 2005).

The above mentioned were the originally defined wastes also known as “Muda” by Taiicho Ohno (Systems2win committee, 2010). With time more wastes are identified and defined. Following are few of them as stated by systems2win, a lean consulting company;

### Confusion

Often confusion is caused when there is missing or misinformation. This causes uncertainty when it is time to take the right decisions regarding a smooth flow of work. Confusion slows down the process and hence it is considered a waste

### Unsafe or Un-ergonomic

Work conditions that compromise the health and productivity of workers in anyway is non-value adding. Some of the examples include carpel tunnel syndrome, eye fatigue, chronic back pain, or other work related medical conditions.

### Underutilized human potential

This type of waste can occur due to various reasons such as

- Restricting employee's authority and responsibility
- Highly paid staff for routine work
- Not expecting everyone to be part of continuous improvement

## 1.2. Introduction to Lean Construction

### *1.2.1. History of Lean Production*

Lean Production was developed by Toyota led by Engineer Ohno. The term lean was coined by the research team working on international auto production to reflect both the waste reduction nature and to contrast it with craft and mass forms of production. The basic idea behind lean production is the elimination of inventories and other wastes through small lot production, reduced set up times, semiautonomous machines, cooperation with suppliers, and other techniques (Monden 1983, Ohno 1988, Shingo 1984). Ohno shifted the attention from the narrow focus of craft production on worker productivity and mass production on the machine to the entire production system. Like the work of Henry Ford, Ohno continued the development of flow based production management. Though, Ohno followed the work of Henry Ford, he did not have an unlimited demand for a reduced machine set up time. Instead, he wanted to build cars according to the customer needs. He started off with reducing the efforts to machine set up time and influenced by Total Quality Management (TQM), he developed a simple set of objectives for the design of the production system: Produce a car to the requirements of a specific customer, deliver it instantly, and maintain no inventories or intermediate stores.

Lean thinking forces attention on how value is generated than how any one activity is managed (Howell et.al, 1990). Currently, a project is viewed as the combination of activities by the current project management. But lean thinking views the entire project as in production system terms as if the project were one large operation.

Lean production presents a very different model. Production is managed so that actions are aligned to produce unique value for the customer. The total duration and cost of the project is made more important than the cost or duration of any activity. Coordination is accomplished in general by the central schedule while the details of work flow are managed throughout the organization by people who are aware of and support project goals (as opposed to activity or local) performance (Howell, 1990). Value to the customer and throughput, the movement of the information or materials to completion are the primary objectives of lean production theory.

In a production system, waste is defined by the performance criteria. If the unique requirements of a client as in time beyond instant and inventory standing idle are not met, then this is defined as waste (Howell, et.al, 1990). Waste can be reduced by reducing the difference between the current situation and perfection i.e., the customer unique requirements can be met in zero time with nothing in stores and improve the results.

The improvement focus from the activity is shifted to the delivery system by moving towards zero waste or perfection (Howell,1999). When Ohno visited US with other Japanese engineers to learn more about mass production of the cars by visiting the car Plants, all he saw was waste at every stage of the production. Each machine was running at maximum production and in turn led to extensive intermediate inventories, which he called it “waste of overproduction”. He observed that the pressure to keep the assembly line moving was building in defects into the car. The defects were left in the car as the line moved down the line. These defects disrupted down stream work and left completed cars riddled with embedded defects. The US approach believed in minimizing the cost of each part and car by keeping the machines running and the line moving. But Ohno's system design criteria set a multi dimensional standard of perfection that prevented sub-optimization and promoted continuous improvement.

Zero time requirement of a car meeting customer requirements, with nothing in inventory required tight coordination between progress of each car down the line and the arrival of parts from the supply chain. Rework due to errors could not be tolerated as it reduced throughput, the time to make a car from beginning to end, and caused unreliable workflow. And coordinating the arrival of parts assigned to a particular car would be impossible if the movement of the car was unreliable.

Engineer Ohno went so far as to require workers to stop the line on receipt of a defective part or product from upstream. (Only the plant manager could stop the line in US plants.) Working to eliminate rework makes sense from a system perspective, but stopping the line looks very strange to people who are trying to optimize performance of a single activity. Stopping the line made sense to Ohno because he recognized that reducing the cost or increasing the speed could add waste if variability was injected into the flow of work by the "improvement."

Requiring workers to stop the line decentralized decision-making. He carried this further when he replaced centralized control of inventory with a simple system of cards or bins, which signaled the upstream station of downstream demand. In effect, an inventory control strategy was developed which replaced central push with distributed pull. Pull was essential to reduce work in process (WIP). Lower WIP tied up less working capital and decreased the cost of design changes during manufacturing as only a few pieces needed to be scrapped or reworked (Howell,1999). Large inventories are required to keep production in push systems because they are unable to cope with uncertainties in the production system. And large inventories raise the cost of change.

Ohno also decentralized shop floor management by making visible production system information to everyone involved with production. “Transparency” allowed people to make decisions in support of production system objectives and reduced the need for more senior and central management (Howell, 1999).

As he came to better understand the demands of low waste production in manufacturing, he moved back into the design process and out along supply chains. In an effort to reduce the time to design and deliver a new model, the design of the production process was carefully considered along with the design of the car (Howell, 1999). Engineering components to meet design and production criteria was shifted to the suppliers. New commercial contracts were developed which gave the suppliers the incentive to continually reduce both the cost of their components and to participate in the overall improvement of the product and delivery process. Toyota was a demanding customer but it offered suppliers continuing support for improvement (Howell, 1999).

Lean production continues to evolve but the basic outline is clear. Design a production system that will deliver a custom product instantly on order but maintain no intermediate inventories. The concepts include (Howell, 1999):

- Identify and deliver value to the customer value: eliminate anything that does not add value.
- Organize production as a continuous flow.
- Increase output value through systematic consideration of customer requirements
- Reduce Variability
- Simplify by minimizing the number of steps, parts and linkages
- Increase output flexibility
- Increase process transparency
- Focus control on complete process
- Build continuous improvement into the process
- Perfect the product and create reliable flow through stopping the line, pulling inventory, and distributing information and decision-making.
- Pursue perfection: Deliver on order a product meeting customer requirements with nothing in inventory.
- Benchmark

### *1.2.2.* ***Main Ideas and Techniques of Lean theory (Koskela 1993)***

The Lean concept is young and in constant evolution. New concepts emerge and the content of the old concepts change. But two most important “root” terms are Just in Time (JIT) and Total Quality Control (TQC). Many new concepts have surfaced from *JIT* and *TQC* efforts. All the concepts along with *JIT* and *TQC* are explained below.

**Just in Time (JIT)**

According to APICS dictionary Just In Time is defined as "a philosophy of manufacturing based on planned elimination of all waste and on continuous improvement of productivity". It's an inventory control system, which has also been described as an approach with the objective of producing the right part in the right place at the right time (in other words, "just in time") (Schonberger, 1984). The materials are purchased and the units are produced only as needed to meet the actual demand of the customer demand.

Any activity that adds cost without adding value is defined as waste. It could be due to unnecessary moving of materials, the accumulation of excess inventory, or the use of faulty production methods that create products requiring subsequent rework. The JIT concept helps in improving the profits and return on investments by reducing inventory levels, reducing variability, improving product quality, reducing production and delivery lead times and reducing other costs (such as those associated with machine setup and equipment breakdown) (Koskela,1992).

Traditionally manufacturers forecasted the demand for their products into the future and smoothened out the production to meet the forecasted demand. To maximize the efficiency of producing output, they tried to keep everyone as busy as possible. This resulted in large inventories, long production time, high defects rates, production obsolescence, inability to meet delivery schedules, and (ironically) high costs. These could have been avoided if "just in time" (JIT) manufacturing was adopted.

In a Just in Time environment, the flow of goods is controlled by a *pull system*. It is a concept where each process is manufacturing each component in line with another department to build a final part to the exact expectation of delivery from the customer. The pull System uses Kanban Methods, which is described as visual aid used to show that you have either finished a process, or require work/more materials (Schonberger, 1984). The aim of having a visual aid is that the person, who either feeds work off you or gives you work, becomes apparent of your needs quickly.

### Total Quality Control

Total Quality Control (TQC), is a management tool for improving total performance. The quality movement started with the inspection of raw materials and products using statistical methods. In Japan, the quality movement has evolved from mere inspection to products of total quality control. The term total refers to three extensions (Shingo, 1988):

- Expanding quality control from production to all departments
- Expanding quality control from workers to management
- Expanding the notion of quality to cover all operations in the company

The quality methodologies have developed in correspondence with the evaluation of the concept of the quality. The focus has changed from an inspection orientation (sampling theory), through process control (statistical process control and the seven tools), to continuous process improvement (the new seven tools) and presently to designing quality into the product and process (quality function deployment) (Koskela, 1992).

### Total Productive Maintenance (TPM)

Total productive maintenance is the autonomous maintenance of production machinery by small groups of multi-skilled operators (Nakajima, 1988). Total productive maintenance strives to maximize production output by maintaining ideal operating conditions. The production operators are trained to perform routine maintenance tasks on a regular basis, while technicians and engineers handle more specialized tasks. The scope of TPM program includes maintenance prevention (through design or selection of easy to service equipment), equipment improvements, preventive maintenance, and predictive maintenance (determining when to replace components before they fail). According to Nakajima, without TPM, the Toyota production system could not function.

### Employee Involvement

Employee involvement is extremely important for functioning of any company. Rapid response to problems requires empowerment of workers. Continuous improvement is heavily dependent on day-to-day observation and motivation of the workforce, hence the idea of quality circles (Lillrank and Kano, 1989). In order to avoid waste associated with the division of labor, multi skilled and/or self-directed teams have been established for production/ project/ customer based production.

### Continuous Improvement

The key idea of the continuous improvement is to maintain and improve the working standards through small, gradual improvements. It's a never-ending process. The inherent wastes in the process are targeted all the time for continuous improvement. A continuous improvement strategy involves everyone from the very bottom to the very top, the basic premise being that small regular improvements lead to a significant positive improvement over time. (Koskela, 1992).

The main goal of the continuous improvements is to affect the mindset as well as achieve the improvements of the techniques. In this case, everyone pitches in and receives training in the appropriate skills; responsible for their own efforts, areas and progress of their teams and employees will continuously suggest improvements to meet quality, cost and delivery target improvements. The key idea of continuous improvement is to maintain and improve the working standards through small, gradual improvements.

**Time based Competition**

The process of compressing time throughout the organization for the competitive benefit is known as time based competition (stalk and Hout, et.al, 1989). This is the generalized form of just in time philosophy (JIT philosophy), which is well known by the pioneers of JIT. According to Ohno, shortening of lead-time creates benefits such as decrease in the work not related to processing, a decrease in the inventory, and ease of problem identification (Robinson, 1991). Time based competition has become popular, especially in administrative and information work where the JIT concepts sound unfamiliar.

**Concurrent Engineering**

Concurrent (or simultaneous) engineering deals primarily with the design phase of the project. Though it's based on the similar ideas of JIT and TQC, it did not originate directly from them. The term Concurrent refers to an improved design process characterized by rigorous upfront requirements analysis, incorporating the constraints of subsequent phases into the conceptual phase, and tightening of change control towards the end of the design process. In comparison to the traditional sequential design process, iteration cycles are transferred to the initial phase through teamwork. Compression of design time, increase of the number of iterations and reduction of the number of change orders are three major objectives of concurrent engineering. (Koskela, 1992).

Various tools for concurrent engineering tools have been developed, such as principles and systems used in Design for Assembly and Design for Manufacturability.

**Value based strategy (or management)**

Value based strategy refers to "conceptualized and clearly articulated value as the basis for competing" (Carothers and Adams 1991). Firms driven by value-based strategies are customer oriented, in contrast to competitor-oriented firms. Continuous improvement to increase customer value is one essential characteristics of value-based management.

**Visual Management**

An orientation towards visual control in production, quality and workplace organization is what visual management is about (Grief, 1991). This is one of the original JIT ideas and the goal is to render the standard to be applied and a deviation from it is immediately recognizable by anybody. The core principle of visual management is the ability to understand that, with a quick look at the shop floor what orders are being done, if the production is ahead, on par or behind and what needs to be done next. No orders are missed or lost and everyone knows if they are behind or ahead on the day's production. Shop floor staff will take more self-managing responsibility with this method as day-to-day decisions are handled on the shop floor. Visual management has been systematically applied only recently in the west.

**Re-engineering**

Re-engineering refers to the radical configuration of processes and tasks, especially with respect to implementation of information technology (Hammer, 1990). According to Hammer (1990), recognizing and breaking away from outdated rules and fundamental assumptions are the key issue in re-engineering.

### *1.2.3. Principles of Lean Theory (Koskela, 1992)*

A number of principles for flow process design, control and improvement have evolved. Many principles are closely related, but not on the same abstract level. Some of them are more fundamental while others are more application oriented.

According to Koskela (1992), there was ample evidence to show that these principles help in improving the efficiency of flow processes in production activities considerably and rapidly.

The understanding of these principles is of very recent origin and it is presumed that the growth in knowledge of these principles will be rapid and systematic.

**Reduce the share of non-value adding activities**

A value added activity is that activity that converts material and/or information towards that required by the customer where as a non-value adding activity is that activity that takes time, resources or space but does not add value.

According to Ciampa (1991), experience shows that non-value adding activities dominate most processes. Only 3 – 20% of the processes add value and their share of total cycle time is negligible, say from 0.5% to 5% (Stalk and Hout, 1989). Hence reducing the share of non-value adding activities is a fundamental guideline for any process flow.

The root causes of non-value adding activities are design, ignorance and inherent nature of production. They are explained in detail below.

*1.Design:*

In hierarchical organizations, non-value adding activities exist by design. Whenever a task gets divided into subtasks, the non-value adding activities increase: inspecting, moving, and waiting. Hence the traditional organizational design, which follows this pattern, contributes to non –value adding activities. (Koskela, 1992)

*2.Ignorance:*

Ignorance is the most common source of non-value adding activities in the administrative sphere of production. Most processes are not designed in an orderly manner, but evolved in an ad hoc fashion to their present form. The volume of non-value adding activities are not measured and hence there is no drive to curb them. (Koskela, 1992)

*3. Inherent nature of production:*

Non-value adding activities also exist due to the nature of the production. Work in progress has to be moved from one conversion to the next during which defects emerge and accidents happen. (Koskela, 1992)

In regards to the three root causes discussed above, it is possible to eliminate or reduce the amount of these non-value adding activities. However, one has to be careful while doing this as many non-value adding activities produce value for the internal customers, like planning, accounting and accident prevention. Such activities should not be suppressed without considering whether more non-value adding activities would result in other parts of the process. However activities like accidents, defects and wastes add value to no one and hence they need to be eliminated without any hesitation. (Koskela, 1992)

Most of the time, it is possible to attack the most visible waste just by flow-charting the process, then pinpointing and measuring non-value adding activities.

**Increase output value through systematic consideration on customer requirements**

Increasing out value through systematic consideration on customer requirements is another fundamental principle. Fulfilling customers is the only way of generating value. An inherent merit of conversion will not generate value. (Koskela, 1992).

The practical approach to this principle is to carry out a systematic flow design, where customers are defined for each stage, and their requirements analyzed. Other principles, especially enhanced transparency and continuous improvement, also contribute to this principle (Koskela, 1992).

**Reduce variability**

Variability is present by default in any production process. Even if two products are same, there will be differences between those two items and the resources required to produce them (time, raw material, labor) will vary.

> "Variability is the universal enemy"
>
> - Schonberger (1986)

Variability is not good in a process. The two main reasons to reduce variability are as follows.

- From the customers point of view a uniform product is better. According to Taguchi, any deviation from a target value in the product causes a loss, which is quadratic function of the deviation, to the user and wider society (Bendell, et.al 1989). Thus, reduction of variability should go beyond mere conformance to given specifications.
- Variability, especially due to activity duration, increases the volume of non -Value adding activity. It may easily be shown through queue theory that variability increases the cycle time (Krupka 1992, Hopp et.al, 1990). According to Hoops (1990), there are no records of any variability that is good. They induce redundancy into the project.

Reduction of variability should be considered an intrinsic goal. Alternative expressions for these principles are: (Koskela, 1992).

- Reduce uncertainty

- Increase predictability

The practical approach to decrease variability is made up of the well-known procedures of statistical control theory. Essentially, they deal with measuring variability, then finding and eliminating root causes. Standardization of activities by implementing standard procedures is often the means to reduce variability in both conversion and flow processes. Another method is to install fool-proofing devices ("poke-yoke") into the process (Shingo 1986).

**Reduce cycle time**

Time is a natural metric for flow processes. Time is more useful and universal metric than cost and quality because it can be used to drive improvements in both (Krupka, 1992).

A production flow can be characterized by the cycle time, which refers to the time required for a particular piece of material to transverse the flow. The cycle time can be represented as follows.

Cycle time = Processing time + Inspection time + Wait time + Move time

Compressing the cycle time is the best improvement rationale in the new production philosophy as it forces the reduction of inspection, move and wait time.

In addition to the forced elimination of wastes, compression of the total cycle time gives the following benefits (Schmenner 1988, Hopp et.al 1990):

- Faster delivery to the customers
- Reduced need to make forecasts about future demand

- Decrease of disruptions of the production process due to change orders
- Easier management because there are fewer customer orders to keep track of

Every layer in an organizational hierarchy adds to the cycle time of error, correction and problem solving. This simple fact provides the new production philosophy's motivation to decrease organizational layers, thereby empowering the persons working directly within the flow (Koskela, 1992).

**Simplify by minimizing the number of steps, parts and linkages**

One fundamental problem of complexity is extra cost incurred. If other things are being equal, the very complexity of a product or process increases the costs beyond the sum of individual parts or steps. Another fundamental problem of complexity is reliability: complex systems are inherently less reliable than simple systems. Furthermore, the human ability to deal with complexity is bounded and easily exceeded (Koskela, 1992).

Simplification can be understood as

- Reducing number of components in a product
- Reducing the number of steps in a material or information flow

Simplification can be realized, by eliminating non-value adding from the production processes, and on the hand by reconfiguring value adding parts or steps (Koskela, 1992).

Organizational changes can also bring about simplification. Vertical and horizontal division of labor always brings about non-value adding activities, which can be eliminated through self-contained units (multi-skilled, autonomous teams) (Koskela, 1992).

### Increase output flexibility

Increase of output Flexibility may look may seem to be contradicting simplification at the first glance. However many companies have succeeded in realizing both goals simultaneously (stalk and Hout 1989). Some of the key elements are modularized product design in connection with an aggressive use of other principles, especially cycle time compression and transparency.

### Increase process transparency

The propensity to err, urge to reduce the visibility of errors, and diminishing motivation for improvement are increased with lack of process transparency. Thus, it is an objective to make the production process transparent and observable for facilitation of control and improvement: " to make the main flow of operations from start to finish visible and comprehensible to all the employees" (Stalk and Hout 1989). This can be achieved by making the process directly observable through organizational or physical means, measurements, and public display of information. (Koskela, 1992)

### Focus control on the complete process

The two causes of segmented flow control are as follows:

- The flow traverses different units in a hierarchical organization
- The flow crosses through an organizational border

In both the cases, there is a risk of sub optimization. (Koskela, 1992)

The two requisites for focusing control on complete processes:

- The complete process has to be measured
- There must be a controlling authority for the complete process.

**Build continuous improvement into the process**

The effort to reduce waste and to increase value is an internal, incremental and iterative activity that can and must be carried out continuously. The several methods to institutionalize the continuous improvement are as follows (Koskela, 1992):

- Measuring and monitoring improvement
- Setting stretch targets (e.g. for inventory elimination or cycle time reduction), by means of which problems are unearthed and their solutions are stimulated.
- Giving responsibility for improvement to all employees; every organizational unit should implement steady improvement and be rewarded for the implementation.
- To be constantly challenged by better ways
- Linking improvement to control: improvement should be aimed at the current control constraints and problems of the process. The goal is to eliminate the root of problems rather than cope with their effects.

**Balance flow improvement with conversion improvement**

Both the flow and the conversion have potential scope for improvements in any production process (Koskela, 1992). As a rule,

- The higher the complexity of the production process, the higher the impact of flow improvement
- The more wastes inherent in the production processes, the more profitable is flow improvement in comparison to conversion improvement.

However the potential to improve flow is usually higher than conversion improvement in situations where flows have been neglected for decades. On the other hand, flow improvement can be started with smaller investments, but usually requires longer time than a conversion improvement (Koskela, 1992).

It is often worthwhile to aggressively pursue flow process improvement before major investments in new technology. Later, technology investments may be aimed at flow improvement or redesign.

**Benchmarking**

Benchmarking is the process of comparing one's current performance against the world leader in any particular area (Camp 1989, Compton 1992). It is the process where one's business processes and performance metrics is compared to industry bests and/or best practices from other industries. Quality, cost and time are the typically measured performance indicators. In essence, benchmarking is finding and implementing the best practices in the world. Benchmarking is essentially a goal setting procedure, which tries to break down complacency and not invented here attitude.

## 1.3. Building Information Modeling (BIM)

### *1.3.1. __Introduction__*

Building information modeling can be defined as: “The process that is focused on development and use of computer generated model to stimulate the planning, design, construction and operation of facility. (Azhar, et.al; 2008). It is also defined as “ a digital representation of physical and functional characteristics of a facility” (NBIMS Committee, 2007). BIM is a visualization tool that enhances communication between architectural, engineering and construction industries. The concept is to build a building virtually, prior to building it physically, in order to work out problems and simulate and analyze potential impacts (Smith, 2007).

BIM is slowly taking over 2D CAD and one way wonder what is so different about BIM from 2D CAD. The latter comprises of individual 2D views such as plans, sections and elevations and comprises on graphical entities only (such as lines, arcs and circles). But BIM is an intellectual modeling defined in terms of building elements and systems such as spaces, walls, beams and columns (Azhar, et.al, 2008). The BIM carries all the relevant information related to the building such as physical and functional characteristics and project life cycle information.

**Table 1: Comparison of a 2D based process versus the model-based process**

| 2D Based Process | | Model Based Process |
|---|---|---|
| Linear, Phased | Design | Concurrent, Iterative |
| Paper 2D | Drawings | Digital 3D Object based tied to intelligent data |
| Evaluated over days in 2D | Value Engineering Alternatives | Evaluated in 3D instantly |
| Unclear Elevations | Site Planning | Relief Contours |
| Slow and Detailed | Code Review | Expedited and Automated |
| Light Tables | Design Validation | Clash Detection with Audit Trails |
| 2D drawings | Field Drawings | 2D drawings and perspectives |
| Assembled near Completion | Closeout Documents | Intelligent models for operations and maintenance instructions; constantly updated during construction |
| Stand Alone Activities | Scheduling | Activities linked to Models |
| Limited Scenarios evaluated | Sequence Planning | Extensive Scenarios Evaluated earlier in the process |
| Paper shop drawings | Field Coordination | Overlaying Digital Models using collision detection software |
| Use Manuals | Operation Training | Visual |

*Source: AGC Committee, (2009) The contractor's guide to BIM, Edition 1, pg 12*

The complexity of buildings is growing and it is very important for all the stakeholders to understand, and if possible be part of the building process from conceptual stage through construction and actual operation. Use of BIM facilitates good communication between architect, construction manager, mechanical engineers, electrical and plumbing engineers, subcontractors, and other project team members (Sanvido, 2008). It facilitates precise documentation, faster decision making, improved communication between parties, optimization of resources, more efficient workflow, increased productivity, and decreased errors. Even after the construction phase, valuable information can be used by the facility operator for asset management, space planning, and maintenance scheduling to improve the overall performance of the facility or a portfolio of facilities (NBIMS committee, 2007).

There are myths about BIM such as;

- BIM is only for large projects with complex geometries (AGC committee, 2009)
- BIM is only for large contractors who can afford the investment (AGC committee, 2009)

According the AGC committee, BIM can be used on any project regardless of size and shape. BIM could be implemented anytime and at many phases throughout a project. However, the value of implementation as against the current technology, training, and cost of implementation needs to be considered. Based on this consideration, appropriate areas and levels of detail needed should be considered (NBIMS committee, 2007).

BIM is driving the construction industry towards a "model-based" process and away from "2D based model" process. Today, according the McGraw-Hill market research, almost 50% of the construction professionals are using BIM and the number of BIM users is growing rapidly.

### *1.3.2. Applications of BIM*

The following are some of the current applications of BIM as explained by Azhar, et.al. (2008),

**Visualization**

BIM allows generation of 3D renderings in-house with very little effort. This is very important for visualization of the project

**Fabrication/Shop Drawings**

For various building systems, the shop drawings can be very easily generated as soon as the model is complete. Example: shop drawings of sheet metal ductwork

**Code Reviews**

Fire departments and other official bodies to review the building projects for better results use the BIM drawings.

**Forensic Analysis**

Potential failures can be graphically illustrated using BIM. Example, leaks, evacuation plans etc.

**Facilities Management**

BIM can be used for space renovations, planning and maintenance operations.

**Cost Estimating**

BIM software can be used for accurate detailed estimating. They have built in cost estimating features, which helps in updating the material quantity whenever any changes are made to the model

**Construction Sequencing**

BIM can be used for create an effective schedule of material ordering, fabrication, and delivery of all building components.

**Conflict, Interference and Collision detection**

BIM helps in visually inspecting for all interferences, clashes and collision and thus reduce conflicts.

### *1.3.3. Benefits of BIM*

The benefits of BIM have major impacts on quality control, on-time completion, overall cost, units/man-hour, dollars/unit and safety (Suerman, 2007). Following are some of the currently recognized benefits of BIM;

**Faster and more effective processes**

According to the survey conducted by McGraw-Hill constructions, more than 48% of the owners say that overall project outcomes are of high benefit. There are very few RFI's and field coordination problems. BIM helps transfer information easily. It can be more value added and reused (Azhar et.al., 2008). Also BIM helps in quickly reacting to design or site problems (Eastman, 2008).

### Better Design

The models can be rigorously analyzed, simulations can be performed quickly and performance benchmarked (Azhar, et.al, 2008). There is better communication and understanding from 3D visualization (McGraw Hill construction, 2009).

### Reducing Rework

The problems are fixed early in the design and hence there will be fewer issues in the plans and hence fewer hassles (McGraw Hill construction, 2009). Any design changes entered to the building model is automatically updated. Hence, there will be less rework due to possible drawing errors/omissions (Eastman, 2008). More than 80% of the people surveyed by McGraw Hill construction (2009) agreed that reducing rework is very important and BIM helps in achieving it.

### Better Collaboration

BIM facilitates early participation of all the players and simultaneous work by them. This shortens the design time and also reduces errors and omissions. This also helps reduce cost as value engineering is done simultaneously and not at the end of design process (Eastman, 2008).

**Generation of accurate and consistent 2D drawings at any stage**

Accurate and consistent 2D drawings can be extracted at anytime in the project process. If any changes are incorporated in the model, it is immediately updated accurately and hence fully consistent drawing can be generated as soon as design modifications are entered (Eastman, 2008).

**Early check against design intent**

BIM not only provides 3D visualization but also quantifies material quantities. This helps in accurate and early cost estimating. Hence the design intent of a building both quantitatively and qualitatively can be checked early in the process (Eastman, 2008).

**Controlled whole-life costs and environmental data**

Environmental performance and life cycle costs are more predictable and better understood (Azhar, et.al, 2008).

**Cost estimation possible during design stage**

The BIM helps get the bill of quantities at any stage of the design. These values can be used to get a more accurate cost estimation at early phase of a project. Hence, a better-informed design decisions can be made and also be aware of cost implications of the design (Eastman, 2008).

**Improving energy efficiency and sustainability**

The building model can be linked with energy modeling tool to evaluate energy use and hence provide opportunity to design buildings with better energy efficiency, thus improving the building quality (Eastman, 2008).

**Synchronizing Design and Construction Planning**

The 3D objects in the design model can be linked to the construction plan and hence it is possible to show how the building and the site would look at any point in time (Eastman, 2008).

**Detection of errors and omissions (Clash detection)**

This is the most rated way by which owners save time and money using BIM (McGraw Hill Construction, 2009). In 2D drawings, any changes in one drawing are not updated in other related drawings. This leads to many inconsistency and hence lots of errors and omissions. Lot of these errors is detected only after the work has started at the site, which might lead to many site conflicts, legal disputes and change orders. However, use of BIM eliminates these issues. Conflicts are identified before they are detected at site and hence co-ordination between the designers and the contractors are enhanced. Detection of errors speeds the construction process, reduces costs, minimizes legal disputes and provides a better project process (Eastman, 2008).

**Reducing conflicts and Changes**

The errors and omissions are detected early in the design and hence there will be fewer conflicts and changes. According to the survey conducted by McGraw Hill Construction, engineers feel that reduced conflicts and changes add maximum value to the project.

**Verification, guidance and tracking of activities**

To err is human. Even if the modeling is accurate, there could be some error in the construction due to human error. But use of BIM helps detect these errors quickly and easily even with the traditional method of daily site walks (Eastman, 2008). More sophisticated techniques as the following are evolving to support field verification, guide layout, and track information.

- Laser scanning technology
- Machine-guidance technologies
- GPS technologies
- RFID tags

**Use of design as a basis for fabricated components**

Digital product data can be exploited in the downstream process and be used for manufacturing/assembling of structural systems (Azhar, et.al, 2008). In BIM, the components are already defined in 3D and hence their automated fabrications using numerical control machinery is facilitated. This facilitates accurate off site fabrication and hence reduces cost and construction time. Likelihood of on-site changes is reduced, and then larger components can be fabricated without the worry of later possible dimension change due to other items being constructed (Eastman, 2008). The site is also safer since more items are fabricated off site and trucked to the site keeping onsite trades minimum (Smith, 2007).

**Better manage and operate buildings**

The BIM provides a good source of information for all the systems used in the building, which the owner can use to check if all the systems are working properly as the building is completed (Eastman, 2008). Also, the information about warranty and maintenance on mechanical equipments, control systems and other systems can be provided and thus help a better facility management.

### *1.3.4. Challenges/Barriers for BIM adaptation*

BIM is definitely beneficial to the construction industry. However, it is not perfect and it is still evolving. There are still many challenges and barriers in BIM, which still needs to be resolved.

**Ownership**

Who owns the ownership of model? Legal concerns are presenting challenges as to who owns the multiple design, fabrication and construction datasets, who pays for them and who is responsible for their accuracy (Eastman, 2008). Professional groups such as AIA and AGC are developing guidelines to cover issues raised by the use of BIM technology.

**Responsibility**

Another issue in BIM is it is not clear who has to control the entry of data and be responsible for the inaccuracies. Taking the responsibility can be extremely risky as it may lead to major legal liability issues (Azhar, et.al, 2008). Thus, before BIM technology can be fully utilized, the risks of its use must be identified and allocated and the cost of its implications must be paid for as well (Thompson, et.al., 2007).

**Collaboration and Teaming**

Often the architectural firm may not use the BIM software, which leads to general contractor outsourcing the entire model. This is not only is time consuming but also costly. Also, if members of the project used different modeling software, collaborating with them might be difficult and might cause some loss of information (Eastman, 2008).

**Implementation Issues**

Implementing BIM requires through understanding and a plan for implementation before the conversion can begin (Eastman, 2008).

### *1.3.5. Summary of Existing BIM Case studies*

The table 2 is a summary of 10 case studies that was featured in BIM Handbook (Eastman et.al., 2008). The table includes;

- The project name
- Participants who took part in BIM implementation

- Types on tools used in the project
    - Model generation tools
    - BIM related tools
    - Analysis tools
- Benefits realized by the project due to BIM implementation

**Table 2: Summary of BIM implemented projects [5]**

<table>
<tr><th rowspan="2">Projects</th><th rowspan="2">Participants</th><th colspan="3">Tools</th><th rowspan="2">Benefits</th></tr>
<tr><th>Model Generation tools</th><th>BIM related Tools</th><th>Analysis Tools</th></tr>
<tr><td>General Motors Production Plants[6]</td><td>▪Owner/ developer<br>▪Architect<br>▪Engineer<br>▪Contractor<br>▪Subcontractor/ Fabricator<br>▪Facility Operations/End users</td><td>▪Bently Architecture<br>▪SDS/2<br>▪Design Series<br>▪IntelliCAD</td><td>▪AutoCAD</td><td>▪RAM<br>▪Navisworks</td><td>▪Automatic maintenance of consistency in design<br>▪Accurate and consistent drawing sets<br>▪Earlier Collaboration multiple design disciplines<br>▪Synchronizing design and construction planning<br>▪Discover errors before construction (Clash detection)<br>▪Drive fabrication and greater use of pre-fabricated components<br>▪Co-ordinate and Synchronize procurement</td></tr>
<tr><td>Coast guide facility[7]</td><td>▪Owner/ developer<br>▪Architect<br>▪Facility Operations/End users</td><td>▪Archi CAD<br>▪ONUMA planning system</td><td>▪MySQL</td><td></td><td>▪Support for project scoping, cost estimating<br>▪Scenario Planning<br>▪Lifecycle benefits regarding maintenance</td></tr>
<tr><td>Camino Group Medical Building[8]</td><td>▪Owner/ developer<br>▪Engineer<br>▪Contractor Subcontractor/ Fabricator</td><td>▪Revit Structures<br>▪CAD Duct<br>▪Piping Designer</td><td>▪AutoCAD<br>▪SprinkCAD<br>▪Architectural Desktop</td><td>▪Navisworks</td><td>▪Automatic maintenance of consistency in design<br>▪Accurate and consistent drawing sets<br>▪Earlier Collaboration multiple design disciplines<br>▪Synchronizing design and construction planning<br>▪Discover errors before construction (Clash detection)<br>▪Drive fabrication and greater use of pre-fabricated components<br>▪Co-ordinate and Synchronize procurement</td></tr>
</table>

Table 2 Continued from Previous page

| | | | | | |
|---|---|---|---|---|---|
| **Beijing National Aquatics Center**[9] | ▪Architect<br>▪Engineer Contractor | ▪Bently Structural | ▪3D Studio Max<br>▪Rhino | ▪Strand | ▪Early and accurate visualizations<br>▪Automatic maintenance of consistency in design<br>▪Enhanced building performance and quality<br>▪Accurate and consistent drawing sets<br>▪Earlier Collaboration multiple design disciplines<br>▪Drive fabrication and greater use of pre-fabricated components |
| **SF Federal Office Building**[10] | ▪Owner/ developer<br>▪Architect<br>▪Engineer<br>▪Contractor<br>▪Subcontractor/ Fabricator | ▪Bently Architecture<br>▪Tekla Structures | ▪AutoCAD<br>▪FormZ | ▪Energy Plus | ▪Optimize energy efficiency and sustainability<br>▪Early and accurate visualizations<br>▪Automatic maintenance of consistency in design<br>▪Enhanced building performance and quality<br>▪Checks against design intent<br>▪Accurate and consistent drawing sets<br>▪Earlier Collaboration multiple design disciplines<br>▪Discover errors before construction (Clash detection)<br>▪Life cycle benefits regarding operating costs |
| **100 11th Avenue NYC**[11] | ▪Architect<br>▪Subcontractor/ Fabricator | ▪Digital Project | ▪AutoCAD<br>▪Rhino<br>▪CATIA<br>▪Solidworks | ▪Robot<br>▪Strand | ▪Early and accurate visualizations<br>▪Automatic maintenance of consistency in design<br>▪Accurate and consistent drawing sets<br>▪Earlier Collaboration multiple design disciplines<br>▪Synchronizing design and construction planning<br>▪Drive fabrication and greater use of pre-fabricated components<br>▪Co-ordinate and Synchronize procurement |
| **One Island East Office Tower**[12] | ▪Owner/developer<br>▪Architect<br>▪Engineer<br>▪Contractor<br>▪Subcontractor/ Fabricator | ▪Digital Project | ▪AutoCAD | ▪ | ▪Automatic maintenance of consistency in design<br>▪Enhanced building performance and quality<br>▪Accurate and consistent drawing sets<br>▪Earlier Collaboration multiple design disciplines<br>▪Synchronizing design and construction planning<br>▪Discover errors before construction (Clash detection) |
| **Penn National Parking Structure**[13] | ▪Contractor<br>▪Facility Operations/End users | ▪Tekla Structures | ▪AutoCAD | ▪STAAD Pro | ▪Early and accurate visualizations<br>▪Automatic maintenance of consistency in design<br>▪Checks against design intent |

Table 2 Continued from Previous page

| | | | | | |
|---|---|---|---|---|---|
| | | | | | ▪Accurate and consistent drawing sets<br>▪Synchronizing design and construction planning<br>▪Discover errors before construction (Clash detection)<br>▪Drive fabrication and greater use of pre-fabricated components |
| **Hill wood Commercial Project**[14] | ▪Owner/ developer<br>▪Contractor | ▪ | ▪AutoCAD | ▪Dprofiler | ▪Support for project scoping, cost estimating<br>▪Scenario Planning<br>▪Enhanced building performance and quality |
| **Jackson Federal**[15] | ▪Owner/ developer<br>▪Architect<br>▪Engineer<br>▪Facility Operations/End users | ▪Revit Buildings<br>▪Revit Structures Revit Systems | ▪AutoCAD | ▪US cost<br>▪Navis work | ▪Automatic maintenance of consistency in design<br>▪Enhanced building performance and quality<br>▪Checks against design intent<br>▪Accurate and consistent drawing sets<br>▪Earlier Collaboration multiple design disciplines |

[6] *Chapter 9, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

[7] *Thomas Grasl and Hamed Kashani, Chapter 9.2, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

[8] *Chapter 9.3 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

[9] *Sherif Morad Addelmohsen 2006, Chapter 9.4, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

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[15] *Eliel De La Cruz 2006, Chapter 9.10 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

# Chapter 2: Research Methods and Results

## *2.1. <u>Introduction - Research Methodology</u>*

This thesis is part of a comprehensive study of Lean principles and Building information modeling that is seeking to show that BIM helps achieve leaner construction. Lean is a process whereas BIM is a tool. The main aim of this thesis is to explore if BIM can be used as a lean tool or in other words, BIM helps achieve lean principles and reduce wastes in the construction process.

This research has used three different methods to draw conclusions;

1. Analysis from literature: Drawing analysis from literature on BIM and Lean principles to support that BIM helps in leaner construction
2. Industry data: Drawing Conclusions from existing data of projects from a US general contracting company that has been successfully using both lean and BIM practices for the past few years.
3. Focused interviews: Analysis is drawn from interviewing different professionals in the construction industry with BIM experience

### *<u>1. Analysis from literature:</u>*

The first step in this method was to perform thorough research of various papers, journals, articles written by various researchers on construction wastes, lean principles and methodologies and building information modeling. Around a total of 70 papers, journals, articles etc were thoroughly examined to understand the concepts behind lean construction and Building information modeling.

The research covered various areas such as

- Construction wastes and their types
- History of production theory (lean principles)
- Main Ideas and Techniques of Lean
- Principles of production theory
- Introduction to building information modeling
- Benefits and challenges faced by building information modeling
- Future scope for building information modeling

It is a known fact that lean principles are adopted to reduce avoidable wastes such as the following;

- Waiting time
- Motion waste
- Over-Processing waste
- Over production waste
- Transportation waste
- Inventory waste
- Correction (or defect) waste
- Confusion waste
- Unsafe or Un-ergonomic
- Under-utilized potential

In this step, Building information modeling (BIM) is explored in detail to show how some of the above waste is reduced or eliminated and helps achieve fundamental lean principles such as reducing the share of non-value adding activities, increasing output value through systematic consideration on customer requirements, reducing variability, reducing cycle time, simplifying by minimizing the number of steps, parts and linkages, increasing output flexibility, increasing process transparency, focusing control on the complete process, building continuous improvement into the process, balancing flow improvement with conversion improvement, benchmarking, etc.

This section further continues to show how BIM can be used to implement some of the following existing Lean techniques to reduce waste;

- Just in time (JIT)
- Total Quality Control (TQC)
- Total Productivity Maintenance (TPM)
- Employee Involvement
- Continuous Improvement
- Time based Competition
- Concurrent Engineering
- Value Based Strategy
- Visual Management
- Re-engineering

Finally, ten successful case studies included in the BIM Handbook (Eastman, et.al., 2008)are carefully examined. Real benefits and examples of BIM are picked up from these case studies to show how

- BIM helps reduce waste
- BIM helps implementing lean techniques
- BIM helps achieve lean principles

***<u>2Analysis from Industry Data:</u>***

Construction performance data (e.g., time, cost) was collected from eleven construction projects, with the intention of comparing projects that use BIM with other that do not. However, it was challenging to do live case studies on construction projects due to their long durations. Having identified this problem, the objective of this step was to compare both BIM and non-BIM projects and draw analysis on available data in terms of

- Cost
  - Total project cost
  - Cost due to change orders
  - Savings on construction
- Duration

To achieve this, one of the construction companies ranked in top 50 general contractors in the country were selected. This company is a national commercial contractor and construction manager that have grown over years providing measurably more value.

Due to difficulty in attaining reliable data over large number of projects, as a first step, six projects with BIM implementation were identified to draw some analysis. Then, as a second step, five out these six projects with similar building use (lab and testing) were selected and compared with five non-BIM implemented buildings with the same building use. This was done to eliminate any variability in data due to company principles or building use.

***3. Analysis from Interviews:***

The third method consisted of interviews with working professionals who had either used BIM in the past or were working on projects that used BIM currently. This method was adopted to find the perspective view of these professionals on BIM as a waste reduction tool based on their experience and identifying benefits, challenges and scope for future improvements. The professionals focused for the interview were;

- BIM consultant/Specialists
- Engineers
- Owners
- Construction Managers/Contractors/Subcontractors
- Architects

The interview was designed to identify the following factors and draw conclusions based on their perspective on these factors;

- Copyright of BIM
- Impact of BIM on
    - Time
    - Cost
    - Quality
- Cost of implementing BIM in a project

- Legal liabilities
- Workflow impacts
- Scope for future improvements in BIM

A total of eleven people were interviewed. Though most of the professionals interviewed were from United States, two of the architects practiced in Europe. The location of practice should not make any difference in the results. Table 3 shows the breakdown of number of professionals interviewed.

**Table 3: Breakdown of A/E/C Professionals**

| Professional | Number of people |
|---|---|
| BIM consultant | 3 |
| Engineers | 2 |
| Owners | 1 |
| Construction Managers/Contractors/Subcontractors | 2 |
| Architects | 3 |

After the interview, all the data obtained was arranged in an order and summary of the collective interview was presented as a report under the following topics;

- Perspective of BIM consultant/Specialists based on BIM
- Perspective of Engineers on BIM
- Perspective of Owners on BIM
- Perspective of Construction Managers/Contractors/Subcontractors on BIM
- Perspective of Architects on BIM

After preparing this report based on perspective of each player on BIM through their experience, a summary of wastes, which according to the professionals were reduced by BIM implementation, are identified and tabulated in a table to give a clearer picture.

## 2.2. Method I: Analysis from the literature

***Note:*** *All the tables referred in this section are at the end of this section.*

The construction industry is one of the most inefficient industries losing $15.8 billion dollars yearly in US alone according to a study by NIST due to lack of information sharing and process continuity[17]. Several research efforts have been done to address this problem and with time there has been more effort to implement and explore “lean” production theory in construction.

Jones and Womack coined the phrase “LEAN production” in 1990 to describe the type of manufacturing methods and results achieved by Toyota (Davis D, 2007). As it is in production system, the focus of lean construction is to reduce waste and increase value to the customers and provide continuous improvement (Sacks R, Koskela L, Dave B, Owen R, et.al, 2010). Though originally lean was designed to improve manufacturing process be reducing waste, many of its techniques and principles have found their way successfully into construction, proving to be very beneficial to all the industry players.

A new trend in construction that is proving to be very beneficial to all the players in the industry is BIM. Several BIM and related technologies, which is sometimes called the virtual design and construction, are taking over traditional methods of building process. BIM is driving the construction industry towards a “model-based” process and away from “2D based model” process (AGC committee, 2009)

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[17] *www.bfrl.nist.gov/oae/publications/gcrs/04867.pdf*

Building a virtual model of the building before its actual construction helps in conveying the design intent clearly to the owner. The virtual model eliminates confusions; helps all the players understand the building better in terms of space, function, and cost and market the building better. Hence BIM helps in reducing a lot of waste, resulting in higher rates of return. From the various successful case studies completed so far, it is evident that BIM not only reduces time and cost but also reduces a lot of site conflicts and confusions. Furthermore, it helps reduce a lot of non-value adding activities and provide maximum value to the owner.

BIM is used for various applications such as (Eastman, et.al, 2008) ;

- Visualization
- Fabrication/Shop Drawings
- Code Reviews
- Forensic Analysis
- Cost Estimating
- Construction Engineering
- Conflict, Interference and Collision detection

These applications of BIM help reduce several kinds of waste. For example, visualization helps reduce confusion, which leads to less error and effectively, leads to less rework. Therefore, less waste due to correction, rework and defects. The list of wastes that can be reduced with each application of BIM goes on at each stage of the project.

BIM can be used at any time and at any stage of the project. Depending on its time of implementation, it can help reduce waste from design conceptual stage to facility operation stage. If BIM is implemented early in the design stage, it helps reduce a lot of waste due to confusions, errors and defects and lack of understanding. Lean originally identified 7 types of wastes but recently more wastes are added to this original list. The types of wastes identified in this report are waiting time, motion waste, over-Processing waste, over production waste, transportation waste, inventory waste, correction (or defect) waste, confusion waste, unsafe or un-ergonomic waste, under utilized potential waste.

Table 4 shows types of wastes that can be reduced with the implementation of BIM. The main goal of Table 4 is to show what types of waste are reduced with each application of BIM. These conclusions were drawn from the various articles, journals, and case studies that were examined during the research.

Lean process uses several techniques such as the following to reduce the wastes (Koskela, 1992);

- Just in time (JIT)
- Total Quality Control (TQC)
- Total Productivity Maintenance (TPM)
- Employee Involvement
- Continuous Improvement
- Time based Competition
- Concurrent Engineering

- Value Based Strategy
- Visual Management
- Re-engineering

Many of the BIM applications help in successfully implementing these techniques. For example, BIM facilitates early detection of errors, clashes and collisions; thus helping in achieving high quality. Hence BIM helps in total quality control. Another example is that BIM facilitates co-ordination, which in turn lead to employ involvement. The list of examples can go on and Table 5 was developed to show that some of the applications of BIM help in implementing these lean techniques.

Lean focuses on reducing waste in order to achieve the following principles; reducing the share of non-value adding activities, increasing output value through systematic consideration on customer requirements, reducing variability, reducing cycle time, simplifying by minimizing the number of steps, parts and linkages, increasing output flexibility, increasing process transparency, focusing control on the complete process, building continuous improvement into the process, balancing flow improvement with conversion improvement, and benchmarking.

Interestingly, BIM also aids in achieving many of these principles. For example, reducing duration of the project by detecting collisions and clashes in early part of the design aims to reduce non-value adding activities and give maximum value to the customer. Table 6 was developed to show that applications of BIM helps in achieving many of such fundamental lean principles.

After exploring the existing literature carefully, the ten case studies [3] featured in BIM handbook were carefully examined. These ten case studies successfully implemented BIM and achieved noticeable benefits and cost savings on the project. Tables 7a, 7b, 7c, 7d, 8a, 8b, 8c, 9a, 9b, 9c and 9d identifies various examples and benefits from the case studies to support the following;

- BIM helps reduce waste
- BIM helps implementing lean techniques
- BIM helps achieve lean principles

From all the above research, it is evident that BIM does help in leaner construction.

[3] *Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, John Wiley and Sons, NY, 2008.*

***Table 4: Applications of BIM vs. Wastes in Construction***

| Application of BIM Vs Wastes in Construction | Waiting Time | Motion Waste | Processing and Over-Processing waste | Over production waste | Transportation waste | Inventory waste | Correction (or defect) waste | Confusion | Unsafe or Unergonomic | Under Utilized potential |
|---|---|---|---|---|---|---|---|---|---|---|
| Visualization | | X [3] | X [2,3] | X [2,3] | X [3] | | X [3,4] | X [1,2] | X [3] | X [3] |
| Fabrication/Shop Drawings | X [3] | X [3] | X [3] | X [3] | X [3] | X [3] | X [3,4] | | X [3] | X [3] |
| Code Reviews | | | X [3] | | | | X [3,4] | X [4] | X [3] | |
| Forensic Analysis | | | X [3] | | | X [3] | X [3,4] | X [4] | X [3] | |
| Facilities Management | | X [3] | X [3] | | X [3] | | X [3,4] | | X [3] | |
| Cost Estimating | | | X [3] | | | X [3] | X [3,4] | | | |
| Construction Sequencing | X [3] | X [3] | X [3] | | X [3] | X [3] | X [3,4] | | | X [3] |
| Conflict, Interference and Collision detection | X [3] | X [3] | X [3] | | X [3] | X [3] | X [1,3,4] | X [1,4] | X [3] | X [3] |

[1] *Deke Smith, (2007); AIA: An introduction to Building Information Modeling (BIM), Journal of Building Information Modeling, Fall 2007*
[2] *Azhar, S.; Hein, M; and Sketo, B. (2008). "Building Information Modeling: Benefits, Risks and Challenges", Proceedings of the 44th ASC National Conference, Auburn, Alabama, USA.*
[3] *Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, John Wiley and Sons, NY, 2008.*
[4] *Norbert W.Young Jr, Stephen A.Jones, Harvey M. Berstein, John E. Gudgel, (2009); The Business Value of BIM McGraw Hill Construction Smart Market Report*

*Table 5: Applications of BIM vs. Lean Techniques*

| Application of BIM Vs Lean Techniques | Just in Time | Total Quality Control | Total Productive Maintenance (TPM) | Employee Involvement | Continuous Improvement | Time based competition | Concurrent Engineerin g | Value Based Strategy | Visual Management | Reengineering |
|---|---|---|---|---|---|---|---|---|---|---|
| **Visualization** | X [3] | X [3] | | X [1,2,3] | X [3] | X [3] | X [2] | X [2,3] | X [3] | |
| **Fabrication/ Shop Drawings** | X [3] | X [3] | | | | X [3] | | X [2,3] | | X [2,3] |
| **Code Reviews** | | | | | | | | X [2,3] | | |
| **Forensic Analysis** | | X [3] | | | X [3] | | | X [2,3] | | |
| **Facilities Management** | | X [3] | | | | | | X [2,3] | | |
| **Cost Estimating** | | X [3] | | | X [3] | | X [3] | X [2,3] | | |
| **Construction Sequencing** | X [3] | X [3] | X [3] | | X [3] | X [3] | X [3] | X [2,3] | X [3] | |
| **Conflict, Interference and Collision detection** | | X [3] | | X [2,3] | X [3] | | | X [2,3] | | |

[1] *Deke Smith, (2007); AIA: An introduction to Building Information Modeling (BIM), Journal of Building Information Modeling, Fall 2007*

[2] *Azhar, S.; Hein, M; and Sketo, B. (2008). "Building Information Modeling: Benefits, Risks and Challenges", Proceedings of the 44th ASC National Conference, Auburn, Alabama, USA.*

[3] *Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, John Wiley and Sons, NY, 2008.*

[4] *Norbert W.Young Jr, Stephen A.Jones, Harvey M. Berstein, John E. Gudgel, (2009); The Business Value of BIM McGraw Hill Construction Smart Market Report*

***Table 6: Applications of BIM vs. Lean Principles***

| Application of BIM Vs Lean Principles | Reduce the share of non-value adding activities | Increase output value through systematic consideration on customer requirements | Reduce Variability | Reduce Cycle time | Simplify by minimizing the number of steps, parts and linkages | Increase output flexibility | Increase Process transparency | Focus control on the complete process | Build continuous improvement in the process | Balance flow improvement with conversation improvement | Benchmarking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Visualization | X [1,2,3] | X [1,3] | X [3] | X [2] | X [1,3] | | X [1] | | | | |
| Fabrication/Shop Drawings | X [2,3] | X [2,3] | X [3] | X [2] | X [3] | X [3] | | | | | |
| Code Reviews | X [2,3] | X [3] | X [3] | | | | | X [3] | | X [3] | |
| Forensic Analysis | X [2,3] | X [3] | | X [2] | | | | X [3] | X [1,3] | | |
| Facilities Management | X [2,3] | X [3] | | | | | | | | | |
| Cost Estimating | X [2,3] | X [3] | | X [2] | | | | | X [1,3] | | X [3] |
| Construction Sequencing | X [2,3] | X [3] | | X [2] | X [3] | | | X [3] | | X [3] | |
| Conflict, Interference and Collision detection | X [2,3] | X [3] | | X [2] | | | | X [3] | X [1,3] | X [3] | |

[1] *Deke Smith, (2007); AIA: An introduction to Building Information Modeling (BIM), Journal of Building Information Modeling, Fall 2007*
[2] *Azhar, S.; Hein, M; and Sketo, B. (2008). "Building Information Modeling: Benefits, Risks and Challenges", Proceedings of the 44th ASC National Conference, Auburn, Alabama, USA.*
[3] *Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, John Wiley and Sons, NY, 2008.*
[4] *Norbert W.Young Jr, Stephen A.Jones, Harvey M. Berstein, John E. Gudgel, (2009); The Business Value of BIM McGraw Hill Construction Smart Market Report*

*Table 7.A:*

| Types of Wastes reduced | Projects | | |
|---|---|---|---|
| | **General Motors Production Plants [6]** | **United States Coast Guard [7]** | **Beijing National Aquatics center [9]** |
| **Waiting Time** | 3D digital flow enhanced effcient transition of information to project members | OPS helped people provide rapid response and real time analysis | Small design response time |
| | | | Shorter schedules |
| | | | 3D could have been extracted anytime |
| | | | Steel structure and modeled in only 25 minutes which otherwise could have taken weeks or months |
| **Motion Waste** | Just in time delivery | | |
| **Processing and Over-Processing waste** | High level of prefabrication | | |
| **Over production waste** | High level of prefabrication | | 3D model contained all necessary information and design elements |
| **Inventory waste** | High level of prefabrication | | |
| | No material was stored and hence no congestion/temporary storage or material waste due to uncertainties with quantity takeoff or weather conditions | | |
| **Correction (or defect) waste** | Almost no changes were required during construction | Reduced errors | Triforma Strutural gave a complete and structurally correct model |
| | | | Use of Bently Structural software reduced human errors |
| | | | 3D fabrication models were rebuilt on weekly and sometimes daily structural analysis |
| **Confusion /Under Utilized potential** | 3D digital flow enhanced efficient transition of information to project members | Roadmap was to show various milestones of different activities | |
| **Unsafe or Un-ergonomic** | High level of prefabrication | | |
| | Only few crews working at a time | | |

[6] *Chapter 9, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[7] *Thomas Grasl and Hamed Kashani, Chapter 9.2, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[9] *Sherif Morad Addelmohsen 2006, Chapter 9.4, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

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*Table 7.B: Case Studies - Types of waste reduced*

| Types of Waste Reduced | Projects |
|---|---|
| | Camino Group Medical Building [8] |
| Waiting Time | Plan logistics and sequence installation of prefabricated assemblies |
| | No request for RFI and only 5 site changes |
| | Conflicts were limited to material storage and handling |
| Motion Waste | Just in time was practiced which meant less clutter in the site and fewer hours moving materials |
| Processing and Over-Processing waste | Plan logistics and sequence installation of prefabricated assemblies |
| Over production waste | |
| Transportation waste | Plan logistics and sequence installation of prefabricated assemblies |
| Inventory waste | Just in time was practiced which meant less clutter in the site and fewer hours moving materials |
| | Increased offsite fabrication |
| | Just in time was practiced which meant less clutter in the site and fewer hours moving materials |
| Correction (or defect) waste | Minimal design changes after construction |
| | No request for RFI and only 5 site changes |
| | Less rework (41 out of 25000 trade work hours) |
| | Elimination of clashes |
| Confusion /Under Utilized potential | All important decisions were e made during the design |
| | Better co-ordination with the team |
| | No rush to "get in first" to avoid collision |
| | Elimination of clashes |
| Unsafe or Unergonomic | Lesser number of workers on site |
| | Workers relied on better task visualizations |
| | No rush to "get in first" to avoid collision |
| | Reduced field hours |
| Under Utilized potential | Better co-ordination with the team |
| | BIM facilitated early involvement of subcontractors |

[8] *Chapter 9.3 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

*Table 7.C: Case Studies - Types of waste reduced*

| Types of Waste Reduced | Projects | | |
|---|---|---|---|
| | SF Federal Office Building [10] | 100 11th Avenue, New York City [11] | One Island East Project [12] |
| Waiting Time | | Early review of the design | The team met everyweek to discuss the clashes and errors |
| Motion Waste | | Fabrication was made possible | |
| Processing and Over-Processing waste | | Cost estimating and scheduling was done with more accuracy | |
| Over production waste | | Fabrication was made possible | |
| Inventory waste | | Cost estimating and scheduling was done with more accuracy | |
| Correction (or defect) waste | Model helped energy simulations before construction | Robot software tested for deflection | Many clashes and errors were detected before construction |
| | Mosphosis detected visual conflicts | | Quantities were linked to BIM which updated estimation with changes |
| Confusion /Under Utilized potential | Model helped energy simulations before construction | Early review of the design | The team met everyweek to discuss the clashes and errors |
| | Mosphosis detected visual conflicts | | Many clashes and errors were detected before construction |
| Unsafe or Unergonomic | | Robot software tested for deflection | |
| Under Utilized potential | Problems were identified at an earlier stage | | |

*[10]Hugo A.Sheward, 2007, Chapter 9.5, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
*[11] Paolo Sanguinetti 2006, Chapter 9.6, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
*[12] Sung Joon Suk 2006, Chapter 9.7, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

*Table 7.d: Case Studies - Types of waste reduced*

| Types of Wastes Reduced | Projects | | |
|---|---|---|---|
| | Penn National Parking Structure [13] | Hill wood Commercial Project [14] | Jackson Federal [15] |
| Waiting Time | Issues were clarified immediately using model images over phone | Informed design options to owner early in the design phase | Strong design coordination |
| | | Conceptual estimating was possible | |
| | | Early co-ordination and accurate quantity takeoff helped reduce estimating labor hours | |
| Processing and Over-Processing waste | | Design alternatives were explored with "what if" concept | Acoustical quality was tested with Virtual mockup model |
| | | Early co-ordination and accurate quantity takeoff helped reduce estimating labor hours | |
| Over production waste | | | Strong design coordination |
| Correction (or defect) waste | Visual co-ordination helped eliminate constructability errors | | BIM helped maintain 1% tolerance in total area |
| | | | Acoustical quality was tested with Virtual mockup model |
| Confusion /Under Utilized potential | Connections of the structures were clearly visible avoiding future conflicts | Cost estimate was represented graphically | Strong design coordination |
| | Design Intent was successfully conveyed to the owner | | Acoustical quality was tested with Virtual mockup model |
| Under Utilized potential | | | Strong design coordination |

*13 Chapter 9.8 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
*14 Brent Pilgrim, Stewart Carroll, Betsy Del Monte, Chapter 9.9, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
*15Eliel De La Cruz 2006, Chapter 9.10 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

***Table 8.a: Case Studies - Achieved Lean Techniques***

| Achieved Lean Techniques | Projects | | |
|---|---|---|---|
| | **General Motors Production Plants** | **Coast guide facility** | **Camino Group Medical Building** |
| **Just in Time** | JIT delivery was practiced with no waste on site | | Plan logistics and sequence installation of prefabricated assemblies |
| | | | Just in time was practiced which meant less clutter in the site and fewer hours moving materials |
| **Total Quality Control** | Detailed collision free 3D model made prefabrication and pre-assembly possible | OPS allowed real time decision making | BIM facilitated early involvement of subcontractors |
| | | | Elimination of clashes |
| **Employee Involvement** | All the teams worked on a fully coordinated models leading to good communication | | |
| **Continuous Improvement** | | | Better co-ordination with the team |
| | | | BIM facilitated early involvement of subcontractors |
| **Concurrent Engineering** | | | |
| **Value Based Strategy** | Detailed collision free 3D model made prefabrication and pre-assembly possible | Reduced Cost and time dramatically | All important decisions were made during the design |
| **Visual Management** | | Roadmap was used to show various milestones of different activities | Workers relied on better task visualizations |
| | | Roadmap and OPS proved to be visual decision making tools | |
| **Reengineering** | Kaizen events were organized to eliminate used of 2D reviews and submittals, which accelerated steel mill delivery and MEP orders | | |

[6] *Chapter 9, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[7] *Thomas Grasl and Hamed Kashani, Chapter 9.2, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[8] *Chapter 9.3 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

### *Table 8.b: Case Studies - Achieved Lean Techniques*

| Achieved Lean Techniques | **Projects** | | | |
|---|---|---|---|---|
| | **Beijing National Aquatics Center** | **SF Federal Office Building** | **100 11th Avenue NYC** | **One Island East Office Tower** |
| **Just in Time** | | | | |
| **Total Quality Control** | 3D fabrication models were rebuilt on weekly and sometimes daily structural analysis | Problems were identified at an earlier stage | Robot software tested for deflection | Many clashes and errors were detected before construction |
| | | Mosphosis detected visual conflicts | | The team met every week to discuss the clashes and errors |
| | | 3D model helped in energy simulations and better working environments and energy savings | | Acoustical quality was tested with Virtual mockup model |
| **Total Productive Maintenance (TPM)** | Triforma Strutural gave a complete and structurally correct model | | | |
| **Continuous Improvement** | 3D fabrication models were rebuilt on weekly and sometimes daily structural analysis | Problems were identified at an earlier stage | Robot software tested for deflection | Many clashes and errors were detected before construction |
| | | Mosphosis detected visual conflicts | | The team met every week to discuss the clashes and errors |
| **Value Based Strategy** | | | | Quantities were linked to BIM which updated estimation with changes |
| **Visual Management** | Small design response time | 3D model helped in energy simulations and better working environments and energy savings | Robot software tested for deflection | Many clashes and errors were detected before construction |
| | Issues of sustainability, building performance, fire protection and safety were effectively produced | | Fabrication was made possible | |
| | Constant modeling of evolving and changing structures | | Cost estimating and scheduling was done with more accuracy | |
| **Reengineering** | 3D wireframes helped better visualization | | | |

[9] *Sherif Morad Addelmohsen 2006, Chapter 9.4, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[10] *Hugo A.Sheward, 2007, Chapter 9.5, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[11, 12] *Paolo Sanguinetti 2006,Sung Joon Suk 2006, Chapter 9.7, Chapter 9.6, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

*Table 8.c: Case Studies - Achieved Lean Techniques*

| Achieved Lean Techniques | Projects | | |
|---|---|---|---|
| | **Penn National Parking Structure** | **Hill wood Commercial Project** | **Jackson Federal** |
| **Total Quality Control** | Connections of the structures were clearly visible avoiding future conflicts | Informed design options to owner early in the design phase | BIM helped maintain 1% tolerance in total area |
| | | Design alternatives were explored with "what if" concept | |
| **Employee Involvement** | Connections of the structures were clearly visible avoiding future conflicts | Informed design options to owner early in the design phase | |
| **Continuous Improvement** | Connections of the structures were clearly visible avoiding future conflicts | Informed design options to owner early in the design phase | |
| **Value Based Strategy** | | Design alternatives were explored with "what if" concept | |
| **Visual Management** | Connections of the structures were clearly visible avoiding future conflicts | Informed design options to owner early in the design phase | Virtual reality model was developed |
| | Design Intent was successfully conveyed to the owner | | Acoustical quality was tested with Virtual mockup model |
| | | | BIM helped maintain 1% tolerance in total area |
| **Reengineering** | Visual co-ordination helped eliminate constructability errors | Cost estimate was represented graphically | |
| | Design Intent was successfully conveyed to the owner | | |

[13] *Chapter 9.8 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[14] *Brent Pilgrim, Stewart Carroll, Betsy Del Monte, Chapter 9.9, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[15] *Eliel De La Cruz 2006, Chapter 9.10 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

*Table 9.a: Case Studies - Lean Principles achieved with BIM implementation*

| **Lean Principles achieved with BIM implementation** | **Projects** | |
|---|---|---|
| | **General Motors Production Plants** | **Coast guide facility** |
| Reduce the share of non-value adding activities | Navisworks was used for collision detection. 3000-4000 interferences were detected and resolved | OPS helped people provide rapid response |
| Increase output value through systematic consideration on customer requirements | 3-5% of the project cost was saved due to automated collision detection | Reduced Cost and time dramatically |
| | 3D digital workflow saved 2-4% of the project cost | |
| Reduce Variability | | BIM and supporting software tools helped in standardizing the process |
| | | Data normalization |
| Reduce Cycle time | Project was completed 5 weeks earlier | Roapmap helped communicate the ideal assessment workflow utilizing BIM to capture and store assessment information |
| | Many systems or group of systems were prefabricated | Parametric template based approach helped save a lot of time |
| Increase Process transparency | | Roadmap was to show various milestones of different activities |
| Build continuous improvement in the process | Bently Projectwise was used for communicating and implementing newest models which allowed all team members to access up-to-date information | |

[6] *Chapter 9, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[7] *Thomas Grasl and Hamed Kashani, Chapter 9.2, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

*Table 9.b: Case Studies - Lean Principles achieved with BIM implementation*

| Lean Principles achieved with BIM implementation | Projects | |
|---|---|---|
| | **Camino Group Medical Building** | **Beijing National Aquatics Center** |
| Reduce the share of non-value adding activities | All important decisions were made during the design | Triforma Strutural gave a complete and structurally correct model |
| | Increased offsite fabrication | |
| | No request for RFI and only 5 site changes | |
| | Less rework (41 out of 25000 trade work hours) | |
| Increase output value through systematic consideration on customer requirements | Owner had a greater understanding of the facility | Triforma Strutural gave a complete and structurally correct model |
| | Less rework (41 out of 25000 trade work hours) | |
| Reduce Variability | Minimal design changes after construction | 3D model contained all necessary information and design elements |
| | Workers relied on better task visualizations | |
| Reduce Cycle time | BIM facilitated early involvement of subcontractors | Small design response time |
| | Minimal design changes after construction | Shorter schedules |
| | | Steel structure and modeled in only 25 minutes which otherwise could have taken weeks or months |
| | | Bently's structural capabilities such as automatic drawing extraction dramatically reduced time needed to produce 2D documents |
| Simplify by minimizing the number of steps, parts and linkages | Plan logistics and sequence installation of prefabricated assemblies | Steel structure and modeled in only 25 minutes which otherwise could have taken weeks or months |
| Increase Process transparency | Better co-ordination with the team | |
| Focus control on the complete process | Better co-ordination with the team | 3D fabrication models were rebuilt on weekly and sometimes daily structural analysis |
| | Elimination of clashes | |
| Build continuous improvement in the process | Better co-ordination with the team | Triforma Strutural gave a complete and structurally correct model |
| Balance flow improvement with conversation improvement | Plan logistics and sequence installation of prefabricated assemblies | |

[8] *Chapter 9.3 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[9] *Sherif Morad Addelmohsen 2006, Chapter 9.4, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

*Table 9.c: Case Studies - Lean Principles achieved with BIM implementation*

| Lean Principles achieved with BIM implementation | Projects | | |
|---|---|---|---|
| | **SF Federal Office Building** | **100 11th Avenue NYC** | **One Island East Office Tower** |
| Reduce the share of non-value adding activities | Problems were identified at an earlier stage | Fabrication was made possible | Many clashes and errors were detected before construction |
| | Mosphosis detected visual conflicts | Early review of the design | Quantities were linked to BIM which updated estimation with changes |
| Increase output value through systematic consideration on customer requirements | Problems were identified at an earlier stage | Fabrication was made possible | Many clashes and errors were detected before construction |
| | Mosphosis detected visual conflicts | Cost estimating and scheduling was done with more accuracy | Substantial cost saving due to clash detections |
| | | | Quantities were linked to BIM which updated estimation with changes |
| Reduce Variability | | Fabrication was made possible | |
| Reduce Cycle time | Mosphosis detected visual conflicts | | |
| Increase output flexibility | | Fabrication was made possible | |
| Increase Process transparency | | | The team met every week to discuss the clashes and errors |
| Focus control on the complete process | | Robot software tested for deflection | Virtual reality model was developed |
| Build continuous improvement in the process | Problems were identified at an earlier stage | Robot software tested for deflection | Quantities were linked to BIM which updated estimation with changes |

[10] *Hugo A.Sheward, 2007, Chapter 9.5, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[11] *Paolo Sanguinetti 2006, Chapter 9.6, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*
[12] *Sung Joon Suk 2006, Chapter 9.7, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

***Table 9.d: Case Studies - Lean Principles achieved with BIM implementation***

| **Lean Principles achieved with BIM implementation** | **Projects** | | |
|---|---|---|---|
| | **Penn National Parking Structure** | **Hill wood Commercial Project** | **Jackson Federal** |
| **Reduce the share of non-value adding activities** | Connections of the structures were clearly visible avoiding future conflicts | Informed design options to owner early in the design phase | BIM helped maintain 1% tolerance in total area |
| | Visual co-ordination helped eliminate constructability errors | Early co-ordination and accurate quantity takeoff helped reduce estimating labor hours | Virtual reality model was developed |
| | | | Acoustical quality tested with Virtual mockup model |
| **Increase output value through systematic consideration on customer requirements** | Connections of the structures were clearly visible avoiding future conflicts | Informed design options to owner early in the design phase | BIM helped maintain 1% tolerance in total area |
| | Visual co-ordination helped eliminate constructability errors | Early co-ordiantion and accurate quantity takeoff helped reduce estimating labor hours | Acoustical quality tested with Virtual mockup model |
| | Design Intent was successfully conveyed to the owner | | |
| **Reduce Cycle time** | | Early co-ordination and accurate quantity takeoff helped reduce estimating labor hours | |
| **Simplify by minimizing the number of steps, parts and linkages** | Connections of the structures were clearly visible avoiding future conflicts | | |
| **Increase output flexibility** | | Conceptual estimating was possible | |
| **Increase Process transparency** | | | Strong design coordination |
| **Focus control on the complete process** | Connections of the structures were clearly visible avoiding future conflicts | Design alternatives were explored with "what if" concept | Strong design coordination |
| | | Cost estimate was represented graphically | |

[13] *Chapter 9.8 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

[14] *Brent Pilgrim, Stewart Carroll, Betsy Del Monte, Chapter 9.9, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

[15] *Eliel De La Cruz 2006, Chapter 9.10 BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors; Eastman, C; Teicholz, P.; Sacks, R; and Liston, K. (2008)*

## 2.3. Method II: Analysis from the industry data

BIM is relatively a new tool and the industry is yet to understand all of the benefits of using BIM. From the earlier sections, it is clear that BIM implementation is extremely beneficial to the industry but there are still many unresolved issues that discourage its use by many professionals in the industry. Another major issue and probably the most important one is the lack of expertise in BIM. People are hesitant to explore new technical possibilities and stick to their earlier methods of running the company. The upfront cost of implementing BIM is high and without proper training, it could potentially be a waste of money. As a result, lots of professionals are unwilling to invest in BIM. Furthermore, the people in the industry do not have enough evidence to believe that BIM is beneficial. There are projects that show successful implementation and enough theory to support that. However, the number of projects and companies that use BIM are not sufficient enough to convince the entire industry. It is especially difficult for smaller firms to implement it due to its high cost of initial investment.

In this section, an attempt has been made to prove the benefits of BIM using the data from six live projects of a reputed large general contracting firm with operations in the United States. This firm has been in the business since 1990. It's also ranked among the top 50 GC firms in the Engineering News Record (ENR) top list for the past 10 years. This firm is a long established leader in virtual design and construction (VDC), building information modeling (BIM) and Integrated Project Delivery (IPD). Currently the firm has used BIM on 75 construction projects. Several projects using BIM have been monitored from the beginning to realize its benefits. According to the firm, the following benefits were realized by one of the first projects monitored. It was a 250,000 SF medical office building and adjacent parking garage.

- Estimated savings in project vs. traditional design bid build was over $9 million
- The turnover of the project was 6 months earlier
- Zero MEP/FP conflict RFI's
- Only 43 hours of rework out of 25000 hours reported from MEP/FP trades
- 82% field work plan reliability over more than a year
- Reduction in peak field labor by 30%
- Productivity from 15% - 30% above industry standards for mechanical installation

The data for five completed projects in Atlanta area and one completed project from Phoenix, Arizona were collected to see the benefits of BIM on unexplored projects. The descriptions of the projects are as follows. To maintain the confidentiality of each project, they have been named as project A, B, C, D, E and F.

*Project A*

Preconstruction services were provided to this physiological research laboratory that occupied approximately 6500 SF. The renovation and expansion project enlarged the laboratory into 9000 SF. This lab is part of a reputed educational institute in Atlanta.

*Project B*

A large wholesale data center provider constructs this project, which consists of 11000 SF of raised floor with an electrical capacity of 100 watts/SF.

*Project C*

This project belongs to an educational institute, which consists of two buildings. The first building is designed to house five engineering programs in the facility. It is a 123,000 SF facility that includes 36 labs, 12 classrooms, two seminar rooms and a 200-seat lecture room.

The second building is a 15,000 SF renovation of the present architectural school. The addition consists of three studio spaces and a new auditorium.

*Project D*

Pre-construction and construction management services were provided for this medical center. It is a 205,136-sqft, six-story patient tower expansion of the existing building. It includes several spaces such as (Emergency) ER, Operating room (OR), Post anesthesia care unit (PACU), Intensive care unit (ICU), kitchen etc.

Although this building was designed in two dimensions, the GC modeled all major components of the project's structural, mechanical and electrical systems in 3D to determine, review and prevent potential clash problems. Additionally, the contractor modeled interior components of the building to allow owner to virtually walk critical spaces and make adjustments to locations of medical equipment prior to construction field.

*Project E*

This is a 31,000 SF design build laboratory renovation project. This project includes converting a 9000-sq.ft of lab space into testing laboratory as well as temperature and humidity controlled warehousing, installation of new emergency generator and overhauled mechanical systems including a new chiller and makeup air unit (MAU)/ air handling unit (AHU) providing 100% outside air. The project also includes interior tenant improvements at the administrative areas.

*Project F*

It is a 52,000 SF allied health and conferencing center for an educational institute. This facility is designed to provide medical training programs as well as a 30,000 SF center.

The following project performance data was collected from these six projects:

- Contract Volume
- Number of change orders
- Amount spent on change orders
- Number of RFI's
- Projected Contract
- Total Project Cost
- Planned duration, Actual Duration

All the projects except project C were able to meet the expenses within the allotted budget and even make a profit. Project B made a profit of 6% and saved over 9% of its original budget through change orders. In spite of the change orders, the projects made profit (Figure 1 & 2). However, none of the 6 projects resulted in saving of project duration. In fact they took 6 -30 days more than the planned duration but six projects are not a significant number to draw conclusions on this data.


**Figure 1**

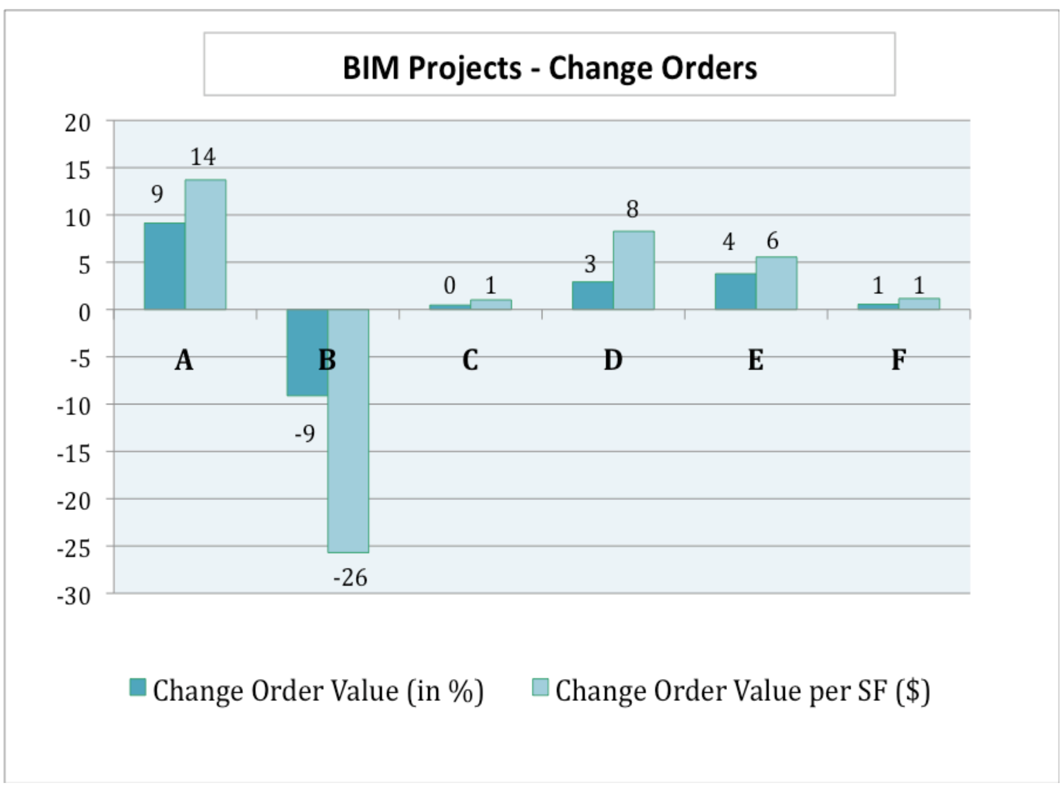


**Figure 2**

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The first five projects A, B, C, D and E are categorized under the building use "lab/testing". Some of them are part of educational institutes. Five random projects by the same GC, which did not implement BIM, were selected to compare with these first five BIM implemented projects. The five non-BIM projects selected were categorized again under "lab/testing". They were selected for their similar building use to eliminate possible source of variation in data due to building use type and company practices.

First the project savings were compared in terms of percentage and amount spent in dollars per square feet (SF) (Figure 3&4). It was observed that projects that implemented BIM either made more profit or no loss compared to projects that did not implement BIM.

Then the amount of dollars spent on change orders in each project was compared (Figure 5&6). Again projects that implemented BIM seemed to comparatively spend less on its change order than projects that did not implement BIM. Interestingly, the projects that did not use BIM were completed earlier than the planned duration except for one project.

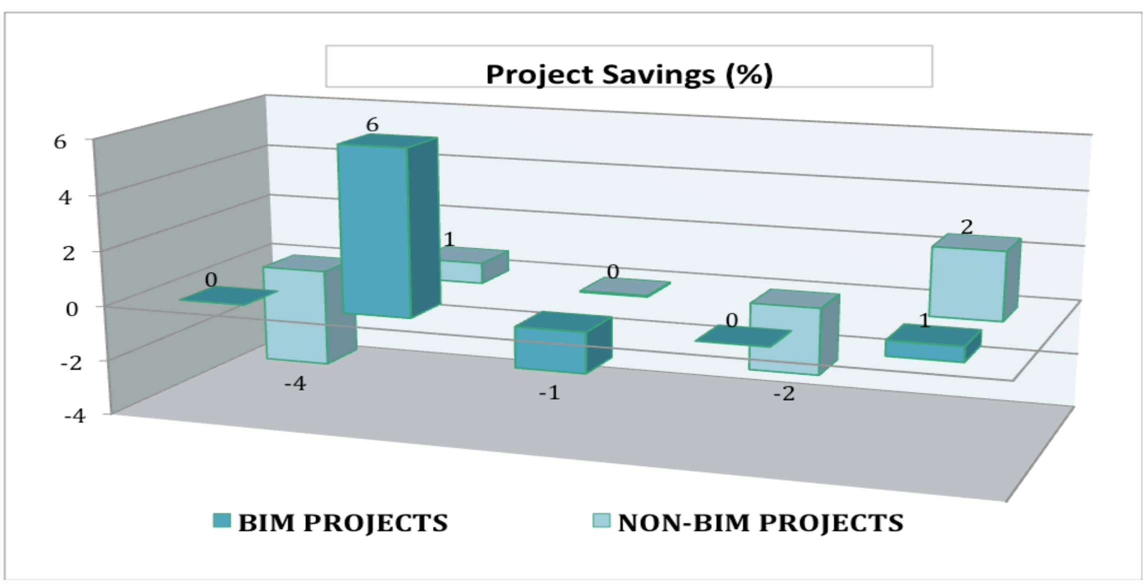


**Figure 3**

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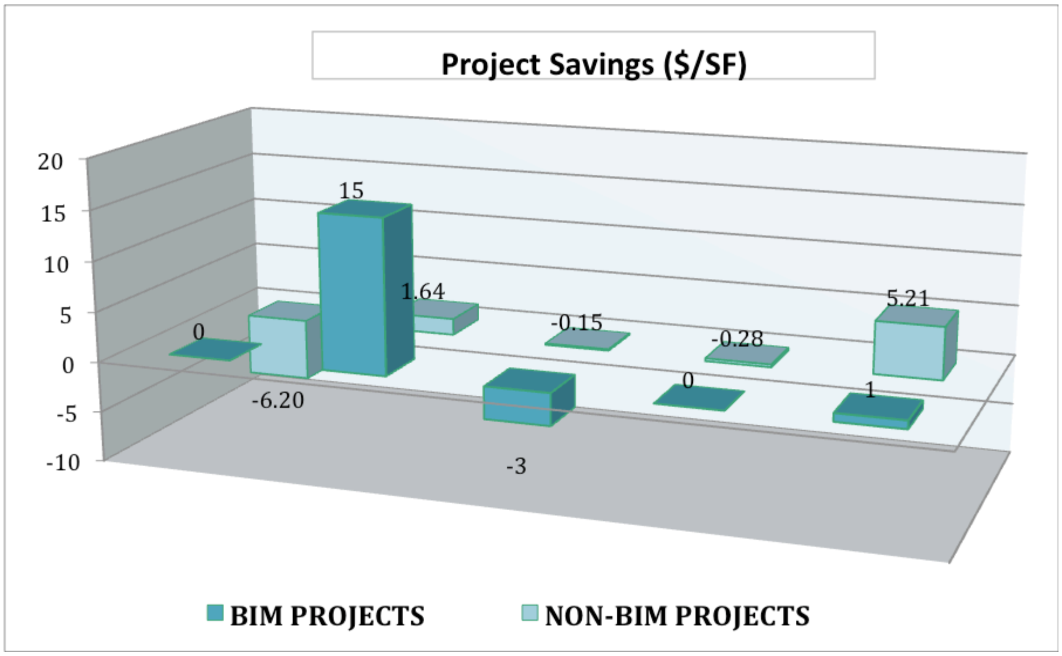


**Figure 4**

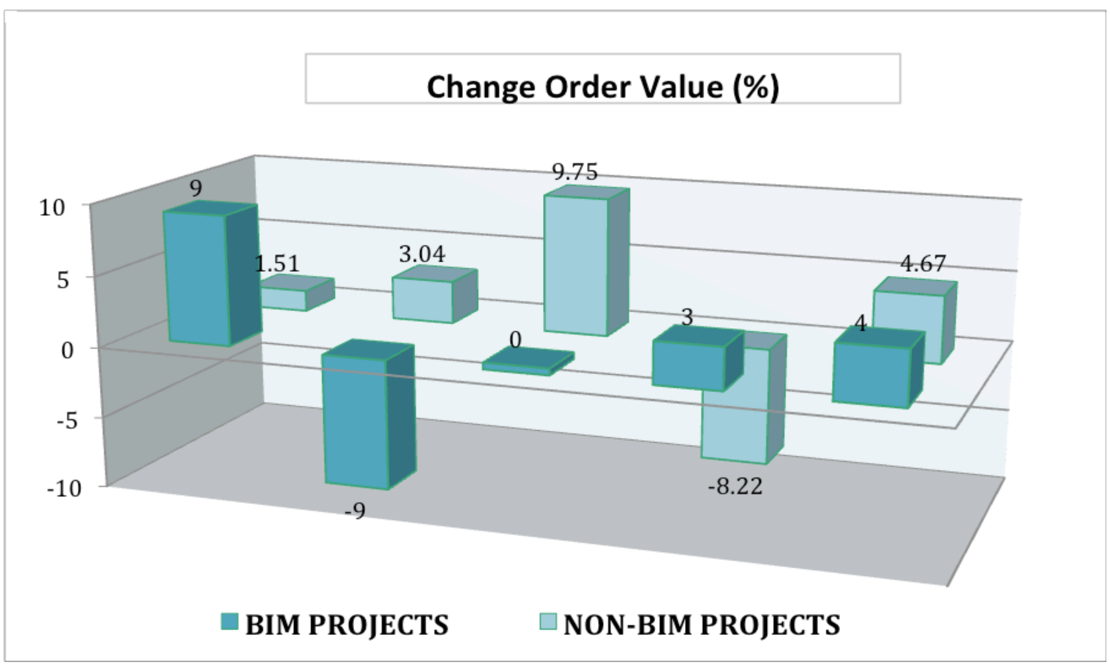


**Figure 5**

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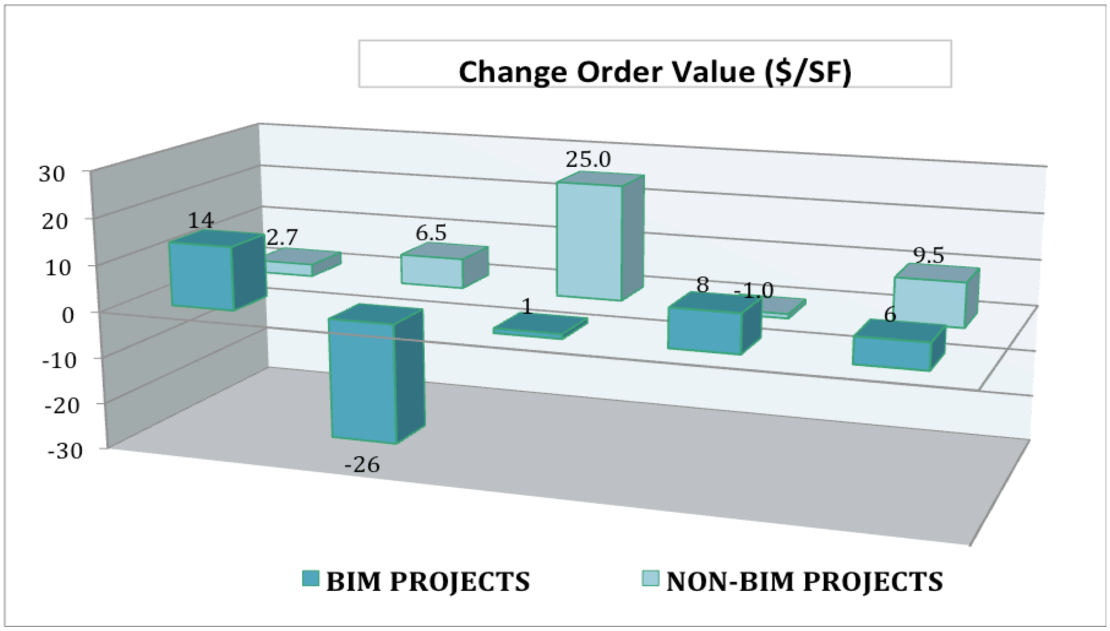


**Figure 6**

Though the tendencies observed in these charts for the majority of projects are clear, the number of projects studied are not significant enough to make a determined conclusion. However, even with this small number of projects, we can observe a slight trend towards saving in project cost and change orders in BIM implemented projects.

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## 2.4. Method 3: Analysis from the interviews

BIM is used to build an accurate virtual model of a building before its actual construction. BIM could be implemented at any stage in a project. Depending on its time of implementation, various professionals take part accordingly. Also, nowadays a lot of organizations are promoting integrated project delivery systems, which facilitates the interaction of all the players in the early design stage of the project.

The purpose of this section is to identify those players in the project who are part of BIM implementation and conduct a detailed interview to get their perspective on BIM as a waste reduction tool based on their experience and identifying benefits, challenges and scope for future improvements.

A total of 11 people were interviewed. The breakdown of each professional type is as follows:

**Table 3: Breakdown of A/E/C Professionals**

| **Professional** | **Number of people** |
| --- | --- |
| BIM Consultant/Specialists | 3 |
| Engineers | 2 |
| Owners | 1 |
| Construction Managers/Contractors | 2 |
| Architects | 3 |

All the eleven professionals interviewed had at least 1-3 years of experience and are successfully implementing on various projects, except for the owner who was relatively new to the use of BIM. The owner is using BIM the first time on two of their building projects.

The three BIM consultants/specialists interviewed were from different BIM consulting companies. All of them are involved in catering BIM service for various architectural and construction related companies. All of them had at least 1 year of experience in this kind of service.

The engineers interviewed worked on various construction projects providing electrical and structural consulting service to the general contractors. One of the engineers claimed to have been involved working with BIM from past ten years.

The two contractors interviewed worked for a general contracting company, which has been promoting the use of BIM from past few years. Both of them had over 3 years of experience working on projects implementing BIM.

The last categories of professionals of a project focused were architects. Three architects who have been using BIM software on their projects from past three years were interviewed. They have worked on various kinds of large-scale commercial projects.

***Perspective of BIM Consultants/Specialists on BIM implementation***

BIM consultants or Specialists focus in providing BIM service to the architects, owners or contractors when there is lack of house expertise in BIM. Since BIM consultants act as external consultants to a project they do not own the copyright to the BIM documents.

There have been no legal implications so far over the BIM documents. The BIM documents sent out are not marked as construction documents. They are used more like reference drawings. People still use 2D drawings as construction documents to avoid legal complications.

*Benefits:* BIM consultants/specialists feel that there are various benefits that are realized by architects, contractors and owners in terms of design efficiencies, construction revision, implementation cost, design sustainability and operability. The data is built over time with progress of the project and hence all data is compiled at the time of handing over the project to the owner. This constant data collection is beneficial to everyone in reducing duplication of work. None of the work needs to be documented or built again. Also, visualization of the building reduces confusions that arise in terms of design, form and function. Since the impacts of the design are known upfront and all the issues are dealt early in the process, the quality of the building will also be better. As a BIM Consultant/ Specialist, the benefit of this technology is limited to profit by providing service. However, they help expedite trade co-ordinations for the other professionals in the industry.

*BIM impact on cost:* BIM helps save a lot project cost especially on those that were spent on rework and change orders. Maximum benefit of BIM can be realized if it is implemented at the early stage of the design and carried until the end of the project. Since BIM initiates more accuracy in design, prefabrication can be carried out earlier without having to wait for current site conditions. Hence, they can be delivered on time saving a lot of cost in construction delay.

The cost on labor is saved, as there is no redundant work. Changes due to design is less as the whole construction can be simulated in BIM. These simulations can show where more labors are working and where are collisions/conflicts in the design in the design early in the project stage.

*BIM impact on time:* BIM plays a major role in reducing the timeframe of a project. For instance, the use of BIM can avoid design development stages and help the project to jump from schematic stage to construction development stage. Also due to clarity of the project, less time is spent on rework, RFI’s and change orders.

*Challenges and Barriers in BIM:* There are few barriers and challenges in BIM that still needs to be addressed. One of the challenges in BIM is that all data must be entered manually. If one piece of data is wrong, it is reflected in all the other related documents and this might lead to a major error in design if not realized by the project team in time. Another major challenge that is faced by the BIM users is coordinating BIM documents of one software tool with another. There are many BIM software tools in the market. Most of the existing BIM software tools are not compatible with each other. Also often the different professionals use different BIM tools. The general contractor (GC) may not use what the architect uses. The general contractor may not have the expertise in the software used by the architect. Hence, often the GC ends up reproducing the documents of the entire project again using other BIM products. Getting all the existing software on the same platform seems to be a big challenge and might take a long time to get over this challenge.

*Types of Waste reduction implied in the interview:*

- Correction (or defects) waste

- Motion waste
- Waiting time
- Confusion
- Over Processing waste
- Over Production waste
- Under/un-utilized potential

***Perspective of Engineers on BIM implementation***

Engineers in construction provide various engineering services such as mechanical, electrical and structural. The GC and not the engineers hold the copyright of BIM, since the GC's are the primary drivers of BIM during construction stage. But again, it depends on the contract. If the Owner is paying for it, then the owner holds the copyright. However, an engineer will have the copyright over individual smaller details, which he has developed to use in several projects. Typically 1-2% of the trade contract value is spent on implementing BIM depending upon complexity of design. No legal liabilities have been encountered so far due to BIM documents.

*Benefits:* BIM promotes better trade co-ordination. It also promotes more accurate field installation documentation. The estimates are more accurate compared to traditional methods. There is better co-relation between estimates and actual installed conditions. BIM helps identifying collision in design and service lines. The 3D visualization helps identify various conflicts and collisions in the service lines. Also new technologies promote use of laser to identify collisions. BIM also facilitates higher use of prefabricated structural elements, thus providing a faster and safer construction. The quality of work observed in BIM implemented projects is much higher due to high clarity of work and collaboration.

*BIM impact on Cost:* Implementation of BIM costs money in the initial stages of the project. However, due to clarity of design and more accurate installation documents, there is a saving on the project cost. Though there is no direct way of measuring the savings due to BIM implementation, past experiences have shown savings on the project cost.

*BIM impact on time:* BIM helps reduce the overall duration of the project. The drawings are constantly updated in all the documents, resulting in less rework and more accurate documents. However, BIM can be better utilized if the GC's plan their schedule for the engineers keeping in mind the time needed to update the BIM documents. Currently, the little time provided by the GC's does not allow proper utilization of BIM.

*Challenges and Barriers in BIM:* The major challenge for BIM is the significant disjoint between different BIM software tools. The A&E teams use different software platform (Revit) and the Subcontract trades use different software platform (AutoCAD). You cannot use these software tools to move back and forth in the design. Also the teams working on them may not have the required skills due to wide variety of software tools available.

*Types of Waste reduction implied in the interview:*

- Correction (or defect) waste
- Confusion waste
- Motion waste

- Over-Processing waste
- Over production waste
- Unsafe or Un-ergonomic waste

***Perspective of Owners on BIM implementation***

Owners may or may not play an important role in the implementation of BIM. However, a GC who drives BIM is more likely to get hired by the owner than others, as the owner feels that it shows greater involvement of GC into the project early in the process. The owner can hold the copyright of BIM documents if and only if it is specified in the contract.

*Benefits:* There are many benefits to BIM. It makes the owner look more sophisticated. BIM also plays a major role in reducing the cost and time of the project. It helps reconfigure an existing building virtually and thus maximizing the potential usage of resources effectively. The visualization helps better understand the design as against 2D drawings and hence encouraging the owner to make the right decisions. BIM facilitates more accurate estimation of building and less contingency, hence resulting in lower project costs. Due to accurate estimating and clarity of design, wastage of material is avoided and lower labor is used. Lower labor helps in achieving safer sites.

There are fewer RFI's and change orders which again help reduce project duration and cost. The conflicts in the documents are easily identified. The design team can explain it's intent clearly so that the owner can make quicker decisions. BIM helps promote a 4D process as against the traditional linear 2D process, thus reducing the project duration.

BIM documents can also be used by the owner for facility management and no separate documents need to be produced for that.

*BIM impact on Cost:* BIM helps reduce the overall project cost. Better understanding of design helps better utilization of resources, and facilitates quicker and right decisions. BIM also gives a more accurate estimate of project that reduces cost on excess materials and labor. BIM is a very beneficial tool to reduce the cost of the project.

*BIM impact on time*: BIM facilitates right and quicker decisions. Also project visualization promotes better and clearer understanding. Furthermore, there are few RFI's and change orders. All these collectively help reduce the overall duration of the project.

*Challenges and Barriers in BIM:* BIM is still an evolving tool and its benefits are not totally realized by all. The industry is currently in a transition period from 2D modeling to 3D modeling. It is not easy to standardize and spread the use of BIM, as there are still many professionals who lack the expertise in using BIM software tools especially in rural areas. They might not have the capital to shift from traditional 2D method to BIM.

*Types of Waste reduction implied in the interview:*

- Waiting time
- Over-Processing waste
- Over production waste
- Inventory waste
- Correction (or defect) waste
- Confusion waste

- Unsafe or Un-ergonomic
- Under utilized potential

***Perspective of Construction Managers/Contractors on BIM implementation***

The construction managers/contractors are very important professionals in the industry. Some of them are initiating the practice of BIM in construction for self-improvement and eliminate waste from their process as practically as possible. A GC can hold copyright of BIM only if they are the drivers of BIM. But if the owner drives the initiative and pays for its implementation, then the owner has the copyright. Copyright issue is dealt during the contract stage and the payers get the copyright.

A GC generally spends around 1-1.5% of the total project cost on BIM implementation. BIM documents are produced either in house or by outsourcing.

*Benefits:* BIM is extremely beneficial especially during the construction stage. All the construction documents produced by BIM can be used as final shop drawings and separate shop drawings don't need to be produced again. The 3D model developed is as built and hence they can be used for pre-fabricating structural elements off site. Also the model helps detect clashes and collisions and reduce conflicts. It helps detect duplicate clashes, soft clashes, clearance and visual inspection.

BIM helps better co-ordination all the elements are color-coded and hence better clarity. Even the underground MEP co-ordinations can be done very effectively. The model provides visualization of intricate details.

BIM helps in better management since there is flow of information and efficient meetings. There are fewer RFI's and change orders. BIM helps achieve higher crew productivity and hence reduction in field modifications. Just in time deliveries is easily managed due to higher reliability on site work. It's safer on the site since there are better planning and reduced field hours. With keeping all the above factors in mind, it's clear that the quality of work will be high during the entire project process.

*BIM impact on Cost:* As stated earlier, BIM helps reduce lot of rework and change orders. The documents don't need to be produced again and again. The information flows from one stage to another and gets updated with every stage. So there is no duplication of work. Hence, BIM helps save the project cost.

*BIM impact on time:* The information flows from one stage to another and gets updated with every stage. So there is no duplication of work. There are fewer RFI's, change orders and field modifications. Many structural elements are prefabricated off site saving confusion and more work on site. Hence, BIM plays a major role in helping reduce the duration of the project.

*Challenges and Barriers in BIM:*

One of the initial challenges in BIM is the upfront cost of implementing it. Many of the subcontractor's might not find it worth spending that cost to work along GC. The challenges of liabilities are still unclear and hence BIM documents are used as reference drawings and not for construction. 2D drawings are still used as construction documents. Human error can cause a major problem as this error could get updated in all the documents and go unnoticed for a long time.

*Types of Waste reduction implied in the interview:*

- Waiting time
- Motion waste
- Over-Processing waste
- Over production waste
- Transportation waste
- Inventory waste
- Correction (or defect) waste
- Confusion waste
- Unsafe or Un-ergonomic
- Under utilized potential

***Perspective of Architects on BIM implementation***

Architects use BIM to convey their design intent better to the owner and check the feasibility of the project in terms of space and function. If the architects produce the BIM documents and if the other professionals to produce documents do not use them, then the architectural firm has the copyright to the model.

*Benefits:* As an architect, one of the biggest benefits is the ability to convey the design intent to the owner better and have better coordination with the consultants. With coordination with the consultants improved, errors and deadlocks are identified at an early stage. Accurate BIM models helps in better solution to design oriented issues and hence better quality.  BIM helps reduce various wastes due to duplication of work and confusions in design.

*BIM impact on Cost:* As an architect, not much cost saving is realized. However, over time it makes the work more efficient and easier.

*BIM impact on time:* The deliverable are met on time. Though it might need some investment of time in the initial stages, the work gets a lot easier and faster at the later stages.

*Challenges and Barriers in BIM:* BIM is still a new tool and most design professionals are still not too comfortable with the use of BIM. If one is not familiar with the work flow then it will lead to cumbersome amounts of unproductive working hours. Also, BIM might restrict the flow ideas for design with time

*Types of Waste reduction implied in the interview:*

- Waiting time
- Over-Processing waste
- Over production waste
- Correction (or defect) waste
- Confusion waste

*From the above summary of interviews conducted among eleven professionals with BIM experience, it is clear that BIM has many positives and also few negatives. Every professional is benefited from BIM is one or the other. BIM helps reduce waste at every stage and the professionals interviewed identified a few wastes that are reduced due to BIM implementation. Table 9 reflects the types of waste identified by the interviewed professionals, which were reduced with the use of BIM.*

**Table 10: Types of Waste reduced by BIM – as identified by A/E/C Professionals**

| Types of waste reduced with BIM | Construction Professionals interviewed | | | | |
|---|---|---|---|---|---|
| | BIM Consultants /Specialists | Engineers | Owners | Construction Managers/ Contractors | Architects |
| Waiting time | X | | X | X | X |
| Motion waste | X | X | | | |
| Over-Processing waste | X | X | X | X | X |
| Over production waste | X | X | X | X | X |
| Inventory waste | | | X | X | |
| Correction (or defect) waste | X | X | X | X | X |
| Confusion waste | X | X | X | X | X |
| Unsafe or Un-ergonomic | | X | X | X | |
| Under-utilized potential | X | | X | X | |

The above table suggests that all A/E/C professionals do perceive BIM as a waste reduction tool. At very stage of a construction project, BIM helps reduce one or the other kind of waste. Be it at initial schematic stage or the operation stage, BIM is definitely playing a major role in reducing waste.

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## Conclusion

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"Does BIM help in leaner construction?"

From the three methods adopted, it was realized that BIM helps in reducing waste. The literature studies, case studies and interviews with BIM experienced A/E/C professionals; all suggest that BIM helps reduce waste in the construction industry.

In the first method, after a careful survey of literature from over 60 articles, journals and books, it was found that BIM plays a major role in lean project delivery. BIM helps implement several lean techniques to achieve several fundamental lean principles which in turn help reduce construction waste.

In the second method, six BIM implemented projects and five non-BIM implemented projects were studied and compared to determine the benefits from the use of BIM. Although the numbers of projects studied was not significant enough to draw conclusions and make significant observations, the results did show a slight inclination towards savings in overall project costs and change order costs in BIM implemented projects.

In the third method, several industry professionals were interviewed to draw conclusions from their first hand experience of BIM with projects. It was clearly seen that every BIM user had realized its benefits and each user implied that BIM did in fact help reduce waste in a construction process. In the end, it was found that BIM helped reduce wastes such as confusion, rework, over production, over processing, unsafe site conditions, under utilized potential, and defects.

With its benefit realized so often, BIM certainly can be used as a waste reduction tool along with many other purposes it is already used for. According to the market survey conducted by McGraw Hill Construction, the use of BIM has increased to 48% in 2009 from 28% in 2007. This trend shows that people are realizing the benefits of BIM more often and soon the majority of the industry will start using it.

It is a known fact that Lean is a process that was originally adopted by the manufacturing industry to reduce waste in the processes adopted. Though several attempts have been made to adopt lean in the construction process, its full benefits have not been realized due to the nature of construction projects. In a traditional construction process, the project is divided into smaller activities, which does not support implementation of Lean process very effectively. However, BIM is helping get over this issue by getting all the professionals involved in the project to participate early in the process and treat the entire project as one process. BIM not only helps detect collisions and provide clear understanding of the design intent, but also helps in making the construction process leaner. With the benefits realized so far by BIM in various construction projects, it is safe to call it a “Lean” tool.

# Appendix

Raw date of the selected BIM and non-BIM projects from the general contracting firm to analyze benefits of BIM in terms of cost and duration

| BIM PROJECTS | Area (SF) | Contract Volume | $ - Change Orders | Projected Contract | Total project cost | Planned Start | Planned Finish | Actual Start | Actual Finish |
|---|---|---|---|---|---|---|---|---|---|
| A | 9000 | 1350000 | 123,349 | 1,350,000 | 1,473,349 | 8/4/10 | 1/5/11 | 8/4/10 | 1/5/11 |
| B | 21000 | 5917456 | -539671 | 5917456 | 5056010 | 11/2/09 | 5/1/10 | 11/2/09 | 5/7/10 |
| C | 138000 | 29908008 | 140988 | 29596033 | 30489960 | 4/28/09 | 9/17/10 | 4/2/09 | 10/14/10 |
| D | 205136 | 58168394 | 1696695 | 60755804 | 59865088 | 2/1/07 | 12/18/08 | 2/1/07 | 1/28/09 |
| E | 40000 | 5,854,939 | 221689 | 6,000,000 | 6,044,255 | 5/13/10 | 9/3/10 | 5/13/10 | 10/27/10 |
| F | 57000 | 12042088 | 200 | 66347 | 200 | 11,996,515 | 12,108,435 | 1/19/09 | 4/16/10 |

| NON-BIM PROJECTS | Area (Sq.Ft) | Contract Volume | $ - Change Orders | Projected Contract | Total project cost | Planned Start | Planned Finish | Actual Start | Actual Finish |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 37000 | 6,200,000 | 98624 | 6,611,604 | 6,527,850 | 1/19/09 | 5/22/09 | 1/19/09 | 5/22/09 |
| 2 | 55000 | 11,500,000 | 357,969 | 11,730,739 | 11,767,591 | 1/8/10 | 5/31/10 | 1/4/10 | 6/2/10 |
| 3 | 170,000 | 39,300,000 | 4,247,697 | 43,572,684 | 43,572,788 | 7/30/03 | 11/22/04 | 7/30/03 | 11/22/04 |
| 4 | 450000 | 5,600,000 | -434,816 | 5,292,720 | 5,292,720 | 9/23/05 | 4/19/07 | 1/12/05 | 9/15/06 |
| 5 | 170000 | 34000000 | 1,620,863 | 34,734,460 | 34,734,460 | N/A | N/A | N/A | N/A |

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